Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 230 AUGUST, 1940 No. 2

WHAT WE HAVE LEARNED FROM SCATTERED X-RAYS.*

BY

ARTHUR H. COMPTON, Ph.D., Sc.D., LL.D.,

Ryerson Physical Laboratory, University of Chicago.

Just as sunlight is scattered by sky and clouds, so x-rays are scattered by any object that they strike. Most of our information about the world has come through light scattered by objects into our eyes. It is thus not surprising that important additions to our knowledge should come from the scattering of the light of super frequency which we call x-rays. The new information thus gained has concerned the nature of x-rays and light, and the nature of the objects which scatter the x-rays.

Only a few months after Rœntgen's announcement of the discovery of x-rays, Michael Pupin, working with an x-ray tube of unusual power, and using Edison's fluoroscope as a sensitive detector, discovered scattered x-rays. He noted that when any object, such as a book or a man's hand, was placed in the x-ray beam, the object itself became a source of radiation which would light up a fluoroscope placed in the neighborhood. It was like brightening a room by placing a sheet of white paper in the path of a sunbeam that comes through a window.

An interpretation of this phenomenon of scattering was

* Read by Dr. Karl Compton, President, Massachusetts Institute of Technology, at Medal Day Meeting, Wednesday, May 15, 1940.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

given some years later by J. J. Thomson in terms of electromagnetic waves acting on electrons. He had already calculated the energy that should be radiated when an electric charge is moving with changing velocity. When x-rays are scattered, he supposed that the electric field of the impinging wave changes the velocity of the electrons in the scattering material. Thus Thomson was able to calculate how intense the scattered rays should be in terms of the number of electrons present.

The calculation was a bold one with far-reaching consequences. Up to this time no satisfactory quantitative test of the theory of radiation from an accelerated charge had been possible. Though the charge and mass of the electron were roughly known, no one knew how many electrons were to be found in each atom. It was, however, correctly assumed that most of the electrons had natural frequencies comparable with those of light, and hence that with regard to x-ray waves of a thousand fold greater frequency they would act almost as if free from constraining forces. A favorable test of Thomson's calculations would thus at once establish the theory that x-rays were electromagnetic waves, that an accelerated charge emits radiation, and, assuming the validity of the theory, serve to estimate the number of electrons in the scattering material.

In 1905 Charles Barkla, stimulated by Thomson's calculations, found a slight polarization of the x-rays coming directly from an x-ray tube, which strongly suggested the electromagnetic character of the rays. Within a year he had performed the then very delicate experiment of measuring x-rays scattered twice at right angles. The first scattering should theoretically polarize the rays completely, and the second scattering of these already polarized rays should serve to analyze their polarization. His experiments showed 50 per cent. polarization as compared with a theoretical 100 per cent., which was adequate to show the strong probability of the correctness of the electromagnetic wave theory of x-rays.

Seventeen years later Dr. Hagenow and I repeated Barkla's work with the more refined equipment then available, and found that the lack of complete polarization which he had observed was due chiefly to multiple scattering in his large po-

larizing and analyzing blocks, and that when smaller blocks are used the polarization does indeed approach 100 per cent. as the theory demands.

It is interesting to note that this first verification of Thomson's theory indicates a motion of the electrons in the scattering material along the direction of the electric vector of the x-ray wave. This shows that the electrons carry electric charges. A few years ago Dr. Rodgers, working in our laboratory, extended the polarization experiments to show that the electron has likewise a magnetic moment. Assuming that an electron is spinning, it should act as a gyroscopic magnet. The magnetic field of an incident x-ray wave should set the resulting magnet in motion in such a way as to produce a scattered ray which has no polarization. This magnetically scattered ray should however be appreciable only for x-rays produced at potentials greater than 200 kilovolts. Using x-rays up to 800 kilovolts potential, where the theoretical value of the scattering by the magnetic doublet of the electron should be comparable with that by its electric charge, Rodgers observed just the expected amount of unpolarized x-rays. Thus scattered x-rays have shown also that the electron is magnetic.

Following his polarization experiments, Barkla measured the intensity of the scattered x-rays. This was found to follow a much more complicated rule than was indicated by Thomson's simple theory. Part of the difference was traced to the fact that in the heavier atoms the electrons are grouped so closely that the scattered x-rays are nearly in phase with each other. This leads to an intensity of scattering greater than Thomson's normal value. On the other hand, for very short x-rays waves, the scattering was found to be less than Thomson predicted, a departure whose origin was not revealed until later.

By carefully selecting the experimental conditions, however, and assuming the essential validity of Thomson's calculations, Barkla was able to make a reliable estimate of the number of electrons in the scattering material. This he found to be a number in each atom equal approximately to half of its atomic weight.

It was one of those striking coincidences of physics that

this first reliable determination of the number of electrons in an atom should have appeared in the same 1911 issue of *The Philosophical Magazine* as that in which Rutherford published his first measurement of the charge on the nucleus of the atom based on the scattering of alpha particles. This charge was likewise estimated as equal to half the atomic weight. At once it became evident that the atom consists of a positively charged nucleus, surrounded by a number of electrons sufficient to neutralize the charge. With Moseley's remarkable x-ray spectra, two years later, we found how the number of these electrons changes merely by one as we go from element to element, the basis of our concept of atomic number, a result which might indeed have been inferred from the earlier experiments of Barkla and Rutherford.

A complete account of what scattered x-rays have taught us would include at this point a consideration of the diffraction of x-rays by crystals and of x-ray spectra, for these are merely especial aspects of scattering. With the work of Laue, the Braggs, Mosely, Siegbahn and many others, however, this work has become so well known that in spite of its outstanding importance we may properly leave it with this passing mention.

My own active interest in scattered x-rays came first when I realized that here was a method of determining the arrangement of electrons in atoms. You are familiar with the ring around the moon caused by the diffraction of moonlight by droplets of fog. In this phenomenon the size of the ring depends upon the ratio of the length of the light wave to the size of the drop. When the size of the corona becomes smaller we know that the droplets are growing, and that very probably they will fall as rain.

In a similar manner x-rays are diffracted by the atoms in a gas, and it should be possible by studying the diffraction halos to estimate the size of the atoms. Since it is the electrons in an atom which scatter x-rays, this would mean finding the distances of the electrons from each other.

It was in 1914 that I began by this direct method to investigate the electronic structure of atoms. The Braggs had been using x-ray diffraction as an effective method of learning the arrangement of atoms in crystals. Why should not a more refined study lead to a knowledge of the electron dis-

tributions in the atoms themselves. The most promising approach seemed at first to study the intensity of the various orders of x-ray diffraction from crystals. C. G. Darwin had made some calculations of intensity of this diffraction in terms of the electron distribution, and I was able to show how it should be possible to calculate backward from observed intensity measurements to arrive at the electron arrangements. The necessary experiments were delicate, and involved many corrections, but were at last completed, only to find that the resulting electron distribution contained an important unknown factor. This factor was the magnitude of the heat motions of the atoms in the crystal that was diffracting the x-rays. Until more was known about the heat motions of atoms, we could not reliably use experiments with crystals to determine the electronic structure of their component atoms.

The obvious alternative to studying atoms arranged in the regular order of a crystal lattice was to use atoms distributed entirely at random. Whereas for the crystal it is necessary to take account of the diffraction pattern of the regularly arranged atoms themselves, for an amorphous substance the diffraction by each moecule should be independent of that of every other, and no such correction for their mutual effects need be considered.

It was from such considerations that in 1917 Debye and Scherrer, working in Switzerland, began to study the diffraction of x-rays by such supposedly amorphous materials as sheets of metal. The result was diffraction patterns showing that these materials were really masses of tiny crystals. Instead of developing a method of determining electronic distributions, therefore, they discovered the powerful and convenient powdered crystal method of studying atomic arrangements in metals.

My own objective was turned toward the scattering of x-rays by monatomic gases, where if under any conditions, one might rely on the random arrangement of the scattering atoms. The first major problem was the experimental one of obtaining enough scattered x-rays to measure. By certain improvements in technique, Barkla had succeeded in measuring reliably the scattering of the total x-ray beam from a large block of solid material. We needed to measure the scattering of a

single wave-length of x-rays from a volume of gas small enough to determine precisely the angle at which the rays were scattered. As compared with Barkla's experiments a factor of roughly a million fold had to be gained.

The problem was precisely similar to that of striving to photograph spiral nebulæ at greater and greater distances. The telescope is made larger, the plates more sensitive, the time of exposure increased, and the aim of the telescope toward the star is improved. So we introduced water-cooled x-ray tubes, ionization chambers with more strongly absorbing gas, an electrometer (which my brother who reads this paper helped to develop) of greatly increased sensitivity, and finally reached the required factor of a million by using P. A. Ross's difference absorption method of obtaining the effects of a homogeneous x-ray beam a hundred times more intense than that reflected from a crystal.

Before this technical difficulty had been overcome, however, we were faced by an unforeseen theoretical problem. When a spectroscope is turned toward the sky, the same Fraunhofer spectral lines are observed as are to be seen when the spectroscope is pointed directly at the sun. This must be so. For every light wave that strikes an air molecule is scattered, and the number of scattered waves will thus be the same as the number of incident ones. This means that the frequency and wave-length of the scattered light must be the same as that of the light that comes from the sun. It had gradually become evident, however, that the diffused x-rays and gamma rays coming from a scattering block were more readily absorbed than the incident rays. Various attempts to explain this phenomenon were put forward, most of them based on the idea that an important part of the diffused rays were of fluorescent origin. When, however, we turned the x-ray spectrometer on the diffused rays we found that almost all of the x-rays were increased in wave-length. Fluorescent rays should not be polarized, but these rays of increased wave-length were. If we were to consider those rays to be scattered whose intensity was given by Thomson's classical theory, certainly we had found a change in wave-length of scattered x-rays. Here was a fundamental difficulty that needed to be resolved before any diffraction theory could reliably be applied

which would assume that the diffracted ray and the primary ray were of the same wave-length.

We soon found that the observed change of wave-length could be quantitatively explained by assuming that the x-ray beam consists of a stream of photons, particles carrying a quantum of energy each, as had been suggested previously by Einstein in his theory of the photoelectric effect. We supposed that each photon is deflected by a single electron, which recoils from the impact, taking away some of the photon's energy. This theory involved thus both the energy and the momentum of the photon, whereas to explain the photoelectric effect only its energy was important.

The theory thus used to account for the change in wave-length implied that scattered x-rays should be accompanied by electrons recoiling with an energy only a few per cent. that of photoelectrons. Such electrons had not yet been identified but were now immediately observed by C. T. R. Wilson, using his cloud chamber, and our studies showed that their number and energy corresponded accurately with the values predicted from the photon theory.

In a desparate effort to save the wave theory of radiation, it was then pointed out that these phenomena were consistent with the view that x-rays are waves if we would consider that the conservation of energy and momentum is only statistically conserved in the scattering process, but not in the motion of the individual electrons. This proposal to abandon the exact validity of the conservation principle stimulated tests by Bothe and Geiger in Germany and by ourselves of the individual process of electron-photon interaction. It was found that whenever a recoil electron appears a photon is scattered in just the direction and with just the energy required for the exact conservation of their energy and the momentum. Thus not only did the conservation principles receive an important new confirmation, but we had actually traced the path of an x-ray from place to place, showing that it travels as a compact bundle of energy. In other words, x-rays were particles.

As these studies were in progress, Louis de Broglie brought forward his now famous theory that the motions of waves and particles are really indistinguishable, if we suppose that associated with each particle is a wave whose length is in-

versely proportional to its momentum. His results were immediately applicable to our experiments on the wave-length change of scattered x-rays. A year or two later they were shown by Davisson and Germer and by G. P. Thomson, to predict accurately the wave properties of electrons. Soon it was found that moving hydrogen and helium atoms and hydrogen molucules can be diffracted by crystal gratings, and that their wave-lengths are also given by de Broglie's theory.

So here was the duality of particles and waves, introduced first in the case of x-rays when our scattering experiments revealed the particle properties of rays long known to be waves, and then extended by de Broglie's theory to moving particles of every type.

It would take us too far afield to describe how this duality became the basis of the uncertainty principle, philosophically one of the most significant developments of modern physics. Nor can we stop to describe the development of the new quantum mechanics, which, as Heisenberg showed, could be derived from this principle as a starting point. For our present purpose the significant fact is that within a half dozen years from the first measurement of the change in wave-length of scattered x-rays a new quantum theory of x-ray scattering had been developed in which electrons had only probable, not actual, positions within the atom. Now it was evident that when x-rays are scattered with changed wave-length they act independently of each other. It is only the scattered rays whose wave-length remains unchanged that are affected by the arrangement of the scattering electrons. The theory was now in shape for reliable application to the data on x-ray scattering.

New work on the scattering of x-rays by helium, neon and argon was now undertaken by Charles Barrett and E. O. Wollan in our laboratory and by G. Herzog in Zurich. In helium the electrons were found to be distributed diffusely in a region whose average size is about that specified by Bohr's old orbital theory. In neon, two groups of electrons are identified, and in argon three groups, though the resolving power of the x-ray waves was not sufficient to distinguish clearly between the two inner groups. The results are indeed as definite as if we were looking directly at the atoms with an

x-ray microscope. Though perhaps not so exciting, it was however very satisfying that the electron distributions thus observed are in complete agreement with modern quantum theories of atomic structure, at least if we interpret the wave-function in terms of the probability of electron occurrence rather than as an actual volume density of electricity.

Comparing the new electron distributions from gases with the older ones from crystals it was now possible to estimate the thermal motions of the crystal atoms. We were thus able directly to show that even at the zero point of temperature a motion of the atoms occurs equal to half a quantum of energy in each mode of vibration. This served to distinguish between two forms of quantum theory of heat which had been a vexing question since the early theories of Planck.

So finally, after some twenty years of study by experimenters in this country and Europe, the problem which I had set myself for my doctor's thesis has received an answer. I am happy to have had a part in its solution. Fortunately, my professors did not demand the completion of the problem before they released me from the university halls. It gives me great pleasure that the Franklin Medal committee has seen in my share of this work a worthy contribution to science. I thank you.

X-Ray Pole Inspection a New Engineering Tool.—Most electric utilities have adopted some program of inspecting their distribution and transmission poles, motivated by the current desire to improve service with decreased cost. Boring and probing tests have admittedly not been altogether satisfactory. Myron Zucker of the Detroit Edison Company in *Electrical World*, Vol. 113, No. 12, proposes a new method for pole inspection, one that gives results with engineering accuracy, does not damage the pole and leaves records by which the progress of rot can be studied. This method is to take pictures through the pole, using a modern, light-weight X-ray machine. Sufficient work has been done by the Detroit Edison Company to indicate that X-ray inspection is accurate, practicable and economical, although there are still a number of unsolved problems and unanswered special questions. In determining just how to use the X-ray to show the difference between good and rotten wood considerable work and thought was required. The technique finally adopted was "non-screen" radiography. The X-rays emerging from the pole register directly on a film that is especially sensitive to this wave-length. The film is wrapped in light-proof paper. This simple, practically fool-proof technique yields clear pictures. Early trials showed that good wood absorbed more rays than rotten wood or a cavity, and this was reflected in the film density from which the soundness of wood might be judged. The apparatus was mounted on a mobile unit so that it could be moved from pole to pole. An analysis is made of the film and calculations can be made of the strength which is compared with the load on the pole obtained by simple charts used by the overhead lines department of the company. Poles with insufficient safety factor are condemned.

R. H. O.

THE CAREER OF A RESEARCH CHEMIST.*

BY

LEO H. BAEKELAND, D.Nat.Sc., D.Ch., D.Sc., LL.D.,

Retired President of Bakelite Corporation.

Ladies and Gentlemen:

In the year 1871, when I was about eight years old and a pupil in the public schools of the city of Ghent, Belgium, our teacher fascinated us by reciting the glorious life of Benjamin Franklin. I dared not dream, then, that some day The Franklin Institute would invite me to receive its foremost honor: The Franklin Medal.

In 1882 I was admitted as a student at the University of Ghent. I had already followed the free evening lectures on chemistry and physics offered by the city of Ghent in a public institution similar to the Cooper Institute of New York. These lectures were well frequented by men, young and old, who desired to improve their knowledge. When I was old enough to enter the University, this preliminary knowledge put me decidedly ahead of my fellow students; although they were older than myself.

While still an undergraduate student I obtained the government position of lecture assistant in chemistry. This gave abundant opportunity to do laboratory work and experiments. Furthermore, I received some income by tutoring backward students whose rich parents could afford the expense.

After obtaining my doctor's degree I was appointed Professor of Chemistry and Physics at the Government Higher Normal School of Science in the old city of Bruges; where government school teachers were trained to teach elementary science in the public schools.

Following that, an appointment was given me as Associate Professor at the University of Ghent.

In 1887 I was awarded first prize in the yearly competition among the alumni of the four Belgian Universities. This

* Read at Medal Day Meeting, Wednesday, May 15, 1940.

prize included a traveling fellowship, with which were furnished funds to visit France, Germany, England, and Scotland.

In 1889, I visited New York. Then and there I became acquainted with the genial Professor of Chemistry of Columbia University, Dr. Charles F. Chandler. Besides being an excellent teacher, he was an enthusiastic amateur photographer. He also was a chemical consultant to A. & H. T. Anthony & Company; then the largest photographic supply house in the United States, and of which the Agfa Ansco Corporation is the successor.

It so happened that the Anthony firm desired to engage the services of a chemist, familiar with photography and photo chemicals. Dr. Chandler recommended me, and I accepted the position for one year.

A year later, a retired stock broker offered to back me financially for the manufacture of photographic papers, of my invention. So the Nepera Chemical Company was founded, to be located at Nepera Park, in Yonkers, N. Y., for the manufacture of photographic papers and chemicals.

Among the various products of this company, the most successful was "Velox" paper. It started a new epoch in photographic printing, and is still widely in use today. Velox supplanted the former slow and unreliable method of "sun printing," by which a photographer was never sure when he could deliver his prints. Before the advent of Velox, it was a familiar occurrence to see the photographer or his aid tramping around his garden or around the flat roof of his house, to watch, one after another, his many sun-exposed printing frames until the capricious sun had done its work. Frequently the sun did not appear for several days. Meantime the impatient customers had to wait for their prints, while the photographer blamed the sun.

Velox did away with all these worries—henceforth photographers could be definite and deliver promptly, regardless of the vagaries of sunlight.

In 1899, after making a success of this enterprise, I sold my interests to the Eastman Kodak Company. This enabled me to devote myself again freely to chemical research and consultation work at my private laboratory in Yonkers.

In 1905 I undertook a new line of research, which resulted

in the invention of synthetic resins, of which Bakelite is best known.

Earlier investigators had been trying unsuccessfully to produce substitutes for the natural resins, such as shellac, amber, copal, etc. My line of approach to this problem was rather different, and resulted in the synthesis of phenolic resinoids. Their properties classified them as a super-resin, of which Nature had not furnished a prototype. Contrary to other resins, it was neither mined from the earth, nor gathered from plants or insects. Molecular synthesis in the laboratory had produced it.

The publication of my work in 1909 before the American Chemical Society immediately stimulated many chemists to further research in this newly opened field. Since then, endless patents and other publications on this subject have been the result.

The applications of synthetic resins, now better known under the name of plastics, are increasing every day. They range from electrical devices to gears, grinding wheels, airplane propellers, self lubricating bearings, waterproof fabrics, surgical tapes, jewelry and ornamental articles, architectural devices, instruments of precision, telephony, brake linings, varnishes, paints, etc.

I hope I have not bored you too much, and that my various experiences may encourage younger men in finding their own road of life.

Getting Around in the City of the Future.—(*Electrical Engineering*, Vol. 59, No. 4.) CHARLES GORDON, managing director of the American Transit Association, stated at a meeting of the Engineers Club of Baltimore recently that a 60-foot-wide city street when used jointly by automobiles and street cars provides an artery for the movement of more than four times as many people as does the same city street when used exclusively by private automobiles. This means that if we remove the street cars on such a street and devote its space entirely to use by automobiles, we shall require in addition to the old street, more than three new streets of the same width to have the same traffic capacity that we had before making the change, provided we recognize, as we should recognize, that the proper measure of traffic capacity is in fact the number of people moved. To move automobiles in congested areas it has been suggested that we need merely to build double deck highways, to eliminate grade crossing interference. In this respect transportation is satisfactory. But the capacity in number of vehicles per hour that can move past a given point does not go up in proportion with the speed. Available data indicates a certain critical speed of about 30 miles per hour, at which the maximum number of vehicles move through a given artery in a given time. These and many other facts must be borne in mind when considering the city of the future. Through many developments, the transit industry is trying to meet the demand for improved urban transportation. The part that any one mode or vehicle of urban transportation is to play in the future must be judged on the basis of its economic and social value to the community. The subject should be approached first of all as a civic matter. When plans for the improvement of a city's circulatory system are under consideration, the interests of any section, group, or business must be subordinated to the needs of the community as a whole.

R. H. O.

COMBINED STRESS EXPERIMENTS ON A NICKEL-CHROME-MOLYBDENUM STEEL.

BY

J. M. LESSELLS AND C. W. MACGREGOR,

Department of Mechanical Engineering, Massachusetts Institute of Technology.

ABSTRACT.

Combined static stress experiments are discribed in which thin walled tubes of a nickel-chrome-molybdenum steel are subjected to combined axial tension and internal pressure, and to combined axial compression and internal pressure. The axial loading was applied by means of a 30 ton hydraulic testing machine and the internal pressure by a pendulum dynamometer and pump. Tangential strains were measured by two newly developed hydraulic lateral extensometers, one of which was used in the axial tension experiments and the other in the axial compression tests. These extensometers possess the advantage over previous types for this work in that they measure accurately the average of the tangential strains over a considerable length of the tubes instead of at a single cross-section. Axial strains were measured with a Martens extensometer. Additional torsion tests are described. The experimental results checked well with the recently suggested constant energy of distortion theory of strength.

Most machine parts are subjected to a state of combined stress as contrasted to a simple uniaxial stress distribution. This means that a small element of the material has applied to it stresses in either two or three perpendicular directions. One of the first problems which confronts the designer in the case of combined stress is the calculation by means of the theory of elasticity of the state of stress existing in the particular application. The next step is the choice of a suitable theory of strength to use for this material in order to select the proper dimensions of the part. Quite a number of such strength theories exist [1] and for most stress ratios give different results, some conservative and others on the unsafe side. A strength theory has not yet been devised which agrees well with test results for all materials and for all stress ratios. Hence, the proper selection of such a theory or strength rela-

[1] A. Nádai, "Plasticity," 1931, pp. 59-74. McGraw-Hill Book Company, Inc., New York.

tion must of necessity be based on test results for the particular material in question. Many such tests have been made in the past in order to select the proper strength relation. Although it is not possible in such a short paper to mention all of these, among the more recent tests on ductile metals under combined static stresses may be mentioned those of Lode,[2] Nádai,[3] Taylor [4] and Quinney,[4] Rôs [5] and Eichinger [5] and others. These experiments have been confined mainly to such materials as pure copper, pure nickel, aluminum, bronze and mild steel, and indicate that the so-called constant energy of distortion theory (von Mises-Huber-Hencky theory), which was suggested comparatively recently, checks the best with test results. The development of this theory of strength will be discussed more in detail later on.

Experiments have also shown that the constant energy of distortion theory does not agree well with static test results on more brittle metals such as cast iron. Combined stress fatigue tests made by Gough [6] and Pollard [6] in England have shown that, although fatigue and first yielding under static stresses are different phenomena, this same theory checked tests on mild steel as in the static stress case, but did not agree well for an alloy steel or for cast iron.

In the light of these test results it was felt desirable to extend the previous investigations under static stresses to include such a commercial material as an alloy steel. A nickel-chrome-molybdenum steel was selected of the following analysis:

C	Mn	P	S	Si	Ni	Cr	Mo
0.37	0.63	0.027	0.037	0.29	2.07	1.06	0.35

[2] W. Lode, "Der Einfluss der mittleren Hauptspannung auf das Fliessen der Metalle," Dissertation, University of Göttingen, Germany, 1928.

[3] A. Nádai, "Theories of Strength," *Transactions of the A. S. M. E.*, Vol. 1, July-September, 1933, pp. 111–123.

[4] G. I. Taylor and H. Quinney, "The Plastic Distortion of Metals," *Philosophical Transactions of the Royal Society, London*, Vol. 230, November 1931, pp. 323–362.

[5] M. Rôs and A. Eichinger, "Versuche zur Klärung der Frage der Bruchgefahr," Diskussions-bericht Number 34, Materialprüfungsanstalt an der E. T. H., Zurich, 1929.

[6] H. J. Gough and H. V. Pollard, "The Strength of Metals Under Combined Alternating Stresses," *Proceedings of the Institution of Mechanical Engineers*, Great Britain, Vol. 131, 1935, pp. 3–103.

This material was given a 1640° F. (893° C.) normalizing anneal, a 1340° F. (727° C.) anneal, a 1520° F. (827° C.) quench and a 1200° F. (648° C) draw. It was supplied in solid bar form two inches in diameter, from which several hollow test pieces were machined and then subjected to tests by means of combined internal pressure and axial tension. Some preliminary tests were run on the material in this condition of heat treatment and were reported in a previous communication.[7] These latter tests were confined to cases of combined stress in which the two stresses at right angles were both tension. These tests showed a good agreement for the stress ratios investigated with the distortion energy theory. To extend these results, the remaining bar stock was given a 1200° F. (648° C.) anneal with furnace cooling, further test pieces were prepared for both axial tension and compression combined with internal pressure, and in addition solid torsion test bars were also machined.

It is the purpose of this paper to discuss the method of attack on and the results obtained from these additional tests.

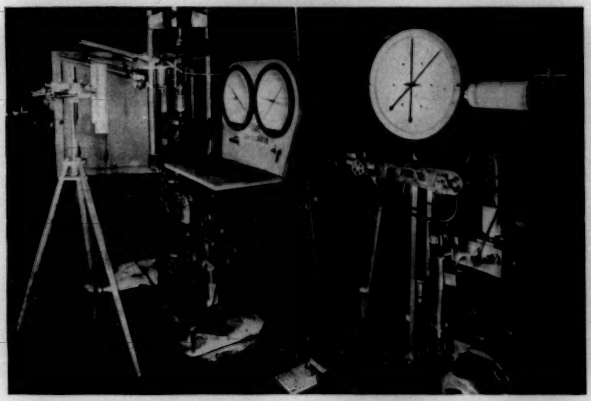
EQUIPMENT FOR COMBINED STRESS TESTS.

Internal pressure was supplied by means of an Amsler pendulum dynamometer and pump of 17,000 lbs./in.^{2} capacity. Axial loads were applied to the tubes by a 30 ton Baldwin-Southwark hydraulic testing machine. The test set-up used when making experiments with axial tension and internal pressure is as shown in Fig. 1. The long tension test piece is indicated in position in the testing machine with a newly developed hydraulic lateral extensometer for measuring tangential strains attached to it. A Martens extensometer was used to measure the axial strains.

A close-up view of the new hydraulic lateral extensometer as applied to the combined internal pressure and axial tension cases is shown in Fig. 2. A diagrammatic sketch of this instrument is included in Fig. 3. Since a discussion of this instrument has been made in a previous paper [7] only a brief description of it will therefore be made herein. Essentially

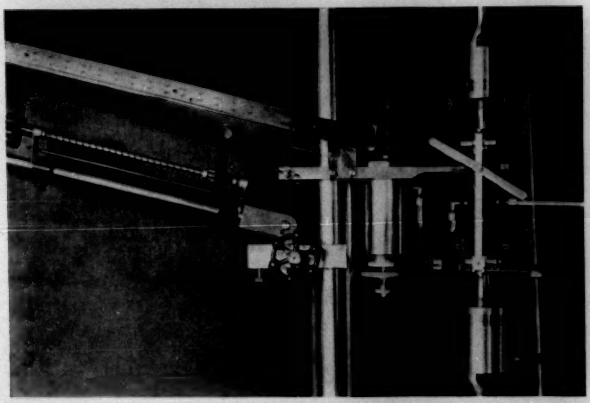
[7] J. M. Lessells and C. W. MacGregor, "Certain Phases of the Combined-Stress Problem," *Proceedings of the Fifth International Congress of Applied Mechanics*, Cambridge, Massachusetts, September 1938, pp. 201–206.

FIG. 1.



Equipment for combined stress tests.

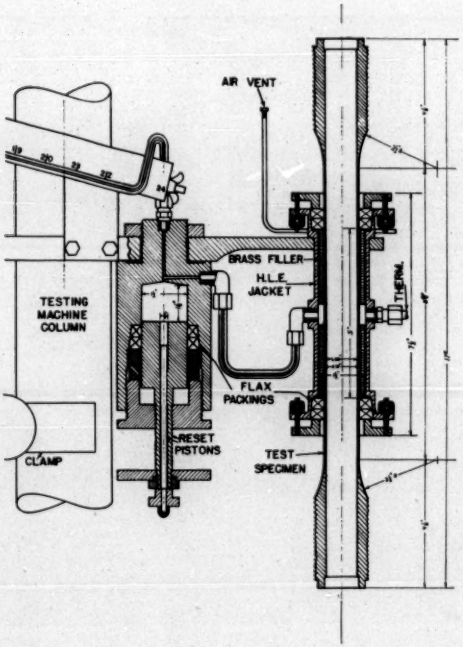
FIG. 2.



Close-up view of hydraulic lateral extensometer for combined tension and internal pressure tests.

it consists of a monel metal jacket surrounding the specimen and filled with water. Flax packings are used to provide water tightness. The jacket is then connected by a glass tube to the monel metal cylinder on the left and attached to a

FIG. 3.

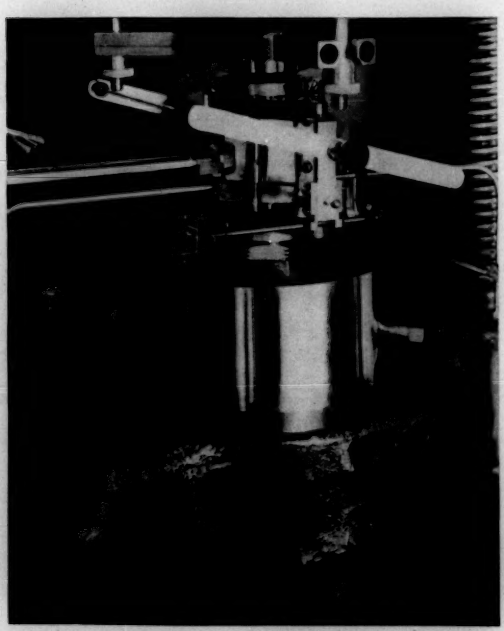


Sketch of hydraulic lateral extensometer shown in Fig. 2. (Tension and internal pressure.)

column of the testing machine for support. Macro and micro adjusting pistons are used in this latter cylinder to change the range of the instrument as well as to provide a zero adjustment. The liquid then proceeds from the top of this cylinder along the inclined glass tube backed by a steel scale graduated

in hundredths of an inch. As the lateral dimension of the test specimen changes under load, a translation of the meniscus is read by means of a cylindrical lens with two parallel cross hairs, the entire lens system being moved parallel to the axis

FIG. 4.



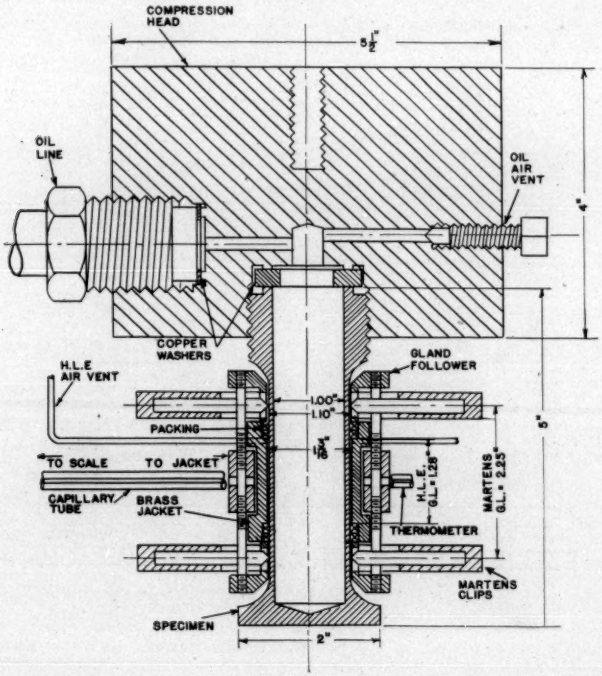
Hydraulic lateral extensometer used for combined compression and internal pressure tests.

of the tube by means of a simple cylindrical cam mechanism. The lateral extensometer so designed possesses several times the sensitivity of the Martens extensometer and has approximately twenty times the range. One inch on the steel scale corresponds to 0.00031 inch/inch lateral strain.

Figure 4 shows the newly developed hydraulic lateral

extensometer used for the combined axial compression and internal pressure tests. Figure 5 gives a diagrammatic sketch showing the construction of this instrument. Essentially the same features are embodied in this instrument as for the

FIG. 5.

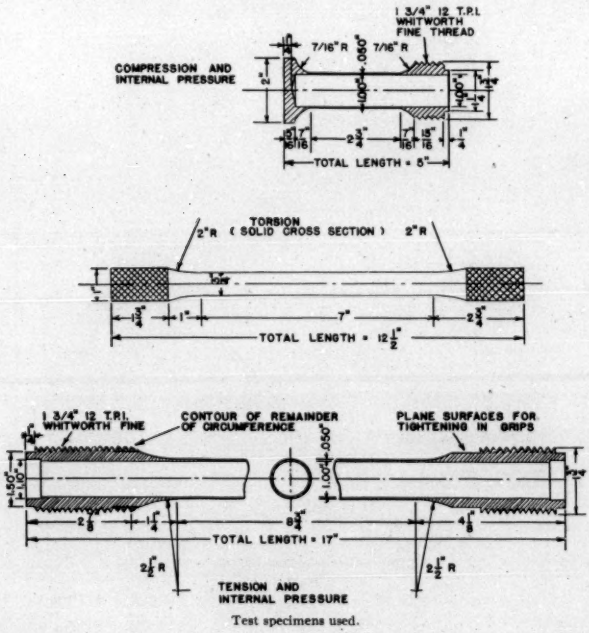


Sketch of lateral extensometer shown in Fig. 4. (Compression and internal pressure.)

tension case except on a smaller scale. The same reset cylinder was used as for the tension instrument and so is not shown. For this instrument one inch on the steel scale corresponds to 0.00123 inch/inch lateral strain. The Martens extensometer strips and mirrors are also shown in position.

In the operation of both lateral extensometers shown in Figs. 2 and 4 certain precautions have to be observed. To eliminate air in the system previously boiled water was used. Further, the water was forced through the upper air vents and bled off at the end of the glass tube. The pistons in the

FIG. 6.



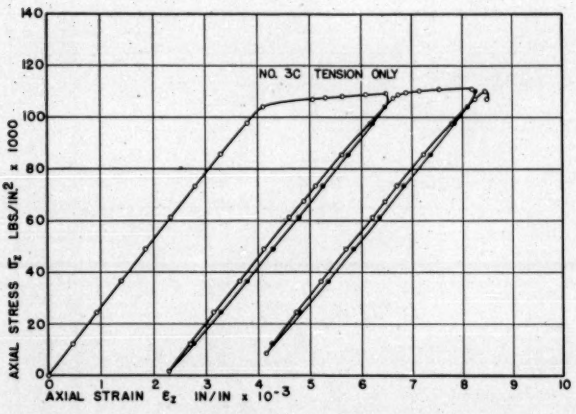
Test specimens used.

adjusting cylinder were moved up and down in order to remove any accumulated air pockets. Pressure was then applied to the end of the glass tube and if appreciable motion of the meniscus was noted, thus indicating entrapped air, the test was not started until this was removed. Trial runs in the elastic range were always made to check the operation

of the instrument. After each run any grease or dirt accumulated in the glass tubes was removed by cleaning with ether. The temperature of the water was measured throughout the test by means of an accurate thermometer. Since the change of temperature was small during a test this involved only a very small correction in the readings.

It is felt that the use of these lateral extensometers overcomes certain objections inherent in some of the earlier tests which have been made using instruments based on the mechanical or optical lever principal. In the latter cases

FIG. 7.



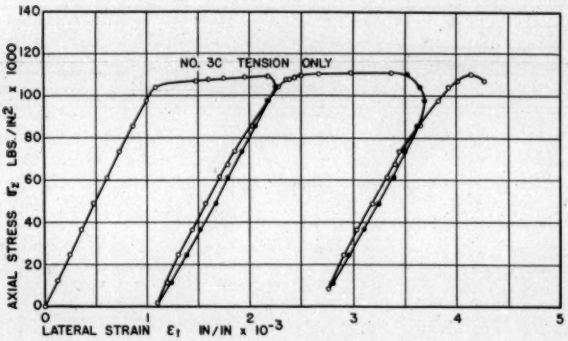
Test specimen No. 3C. Tension only.

readings of tangential strain were made only at one or two cross-sections of the tube. The hydraulic lateral extensometer gives the average tangential strain over a considerable length of the tube.

The thickness of each tube was measured before each run at 9 axial positions along the tube and at every 60 degrees of arc around the circumference by means of a special dial gage and clamp.

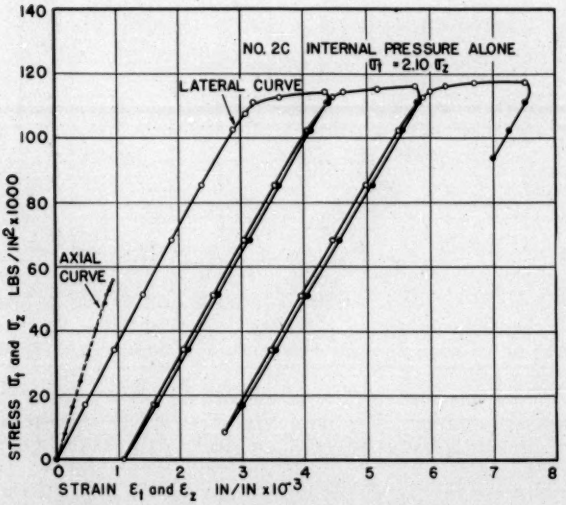
The three types of test pieces used in this investigation are shown in Fig. 6.

FIG. 8.



Test specimen No. 3C. Tension only.

FIG. 9.

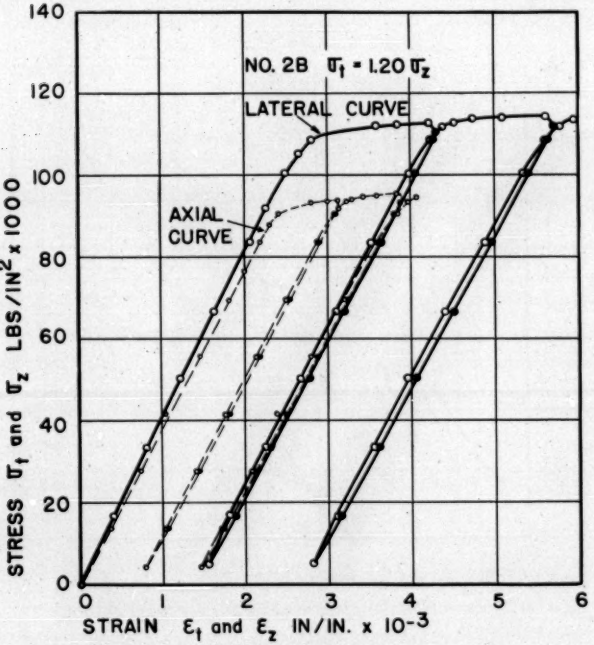


Axial and lateral stress strain curves for specimen No. 2C. Internal pressure only.

EXPERIMENTAL RESULTS.

The stress-strain relations in both the axial and the tangential directions were determined for each tube tested. In each case one or two hysteresis loops were made during

FIG. 10.

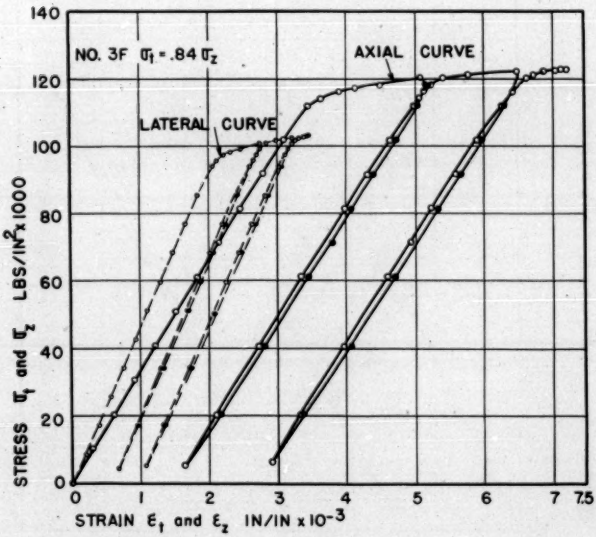


Axial and lateral stress strain curves for specimen No. 2B. Tension and internal pressure.

unloading periods. Only representative types of the tests made will be discussed here. Figures 7 and 8 show portions of the axial stress-axial strain and the axial stress-lateral strain curves received for test specimen No. 3*C* stressed in pure tension only. Figures 9, 10 and 11 give portions of the axial

and lateral stress-strain curves for specimen $2C$ under internal pressure only where $\sigma_t = 2.10\ \sigma_z$, for specimen $2B$ under axial tension and internal pressure where $\sigma_t = 1.20\ \sigma_z$, and for test piece $3F$ under internal pressure and axial tension where $\sigma_t = 0.84\ \sigma_z$ respectively. It will be noted that for internal pressure only the axial strain was almost purely

FIG. 11.

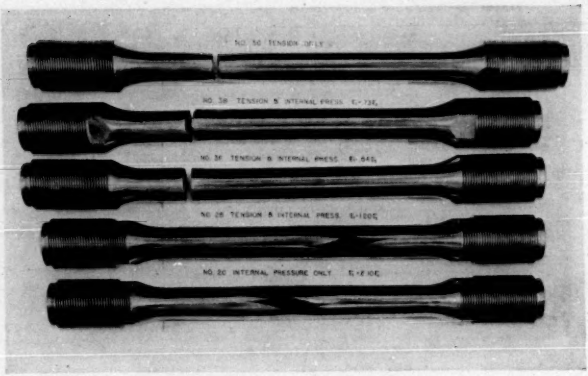


Axial and lateral stress strain curves for specimen No. 3F. Tension and internal pressure.

elastic while considerable plastic lateral strain existed. The fractures received for the various cases where axial tension was applied as well as internal pressure are shown in Fig. 12 which is self-explanatory.

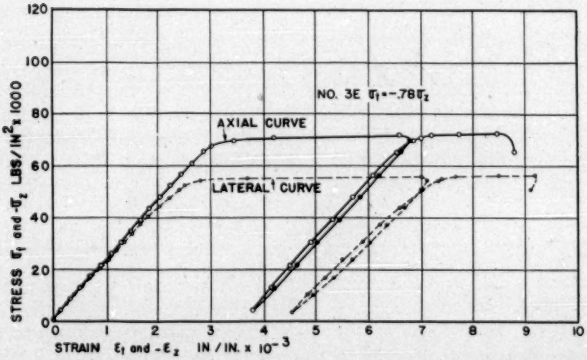
An example of the axial and lateral stress-strain curves received when axial compression is applied in addition to the internal pressure where $\sigma_t = -0.78\ \sigma_z$ is shown in Fig. 13

FIG. 12.



Photograph of fractured test pieces for combined tension and internal pressure tests.

FIG. 13.

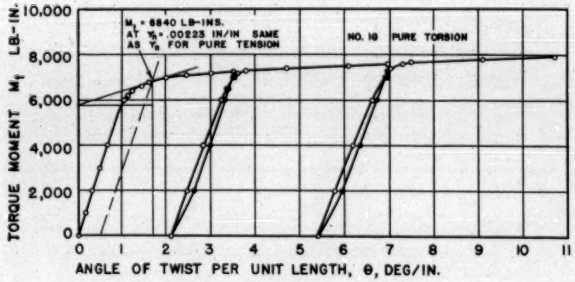


Axial and lateral stress strain curves for specimen No. 3E. Compression and internal pressure.

for specimen $3E$. Specimen $2E$ for which $\sigma_t = -4.31\ \sigma_z$ showed similar curves.

Torsion tests were also made on two solid specimens, the dimensions of which are given in Fig. 6. Torque twist curves were plotted as shown in Fig. 14 for test piece $1G$. This test is naturally also a combined stress test where the element is subjected to tensile and compressive stresses of equal magni-

FIG. 14.



Torque-twist curve for specimen No. 1G. Pure torsion only.

tude at 45 degrees to the axis of the bar, the third principal stress being zero. In these tests the angle of twist was recorded by means of a silk thread stretched between two sectors attached to the straight portion of the test piece. From the torque-twist curve it is possible to readily determine the actual shearing stress present in the outside fibers for any twisting moment in the elastic or plastic state.[8] If τ_a represents this shearing stress, then

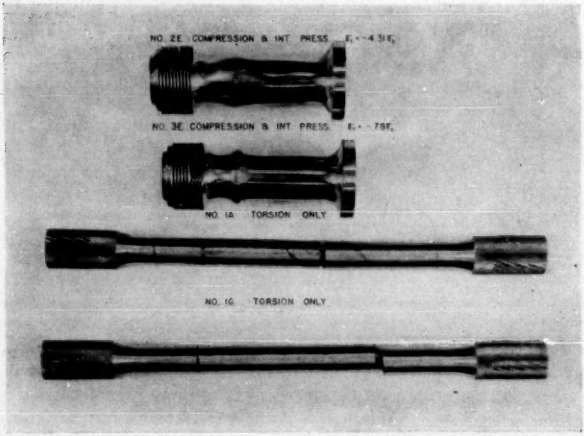
$$\tau_a = \frac{1}{2\pi a^3}\left[3M_t + \theta\frac{dM_t}{d\theta}\right], \qquad (1)$$

where a, M_t and θ are the radius, torque moment, and unit angle of twist respectively. The value of τ_a is equal numerically to the value of the tensile and compressive stresses present at ± 45 degrees to the axis of the twisted bar in the

[8] A. Nádai, "Plasticity," 1931, p. 128, McGraw-Hill Book Company, Inc., New York.

outside fibers. This latter fact comes merely from considerations of the equilibrium of stresses on such an element. The shearing strain γ corresponding to the above shearing stress is equal to $a\theta$. It would then be possible to determine from Fig. 14 the shear stress-shear strain curve for this material. Instead of doing this, however, Fig. 14 is utilized later on to check various strength theories and will be discussed more fully then.

FIG. 15.



View of fractured test pieces for torsion only and for combined compression and internal pressure tests.

The types of fractures received for torsion only and for the combined axial compression and internal pressure cases are shown in Fig. 15.

STRENGTH THEORIES.

From the time that interest is the subject of the strength of materials began, a considerable number of strength theories have been proposed by different investigators. Some of these theories are more or less of academic rather than practical interest and are based on conceptions difficult of interpreta-

tion when referred to ductile engineering metals. In this paper no attempt will be made to discuss each of these theories in the light of the present experiments. However, a few of the more common strength relations will be described herein, and then comparisons will be drawn between the present test results and these theories.

Maximum Stress Theory.—This theory, sometimes called the Rankine theory, states that materials will yield when one of the three principal stresses σ_1, σ_2, σ_3 reaches the yield stress in simple tension σ_0 independently of the values of the other two principal stresses. If $\sigma_1 > \sigma_2 > \sigma_3$ then an analytic expression of this theory is

$$\sigma_1 = \pm \sigma_0. \tag{2}$$

Maximum Strain Theory.—The maximum strain theory was originally suggested by St. Venant in the middle of the last century. The condition of yielding under this theory is defined by the maximum strain. Analytically, then, by Hooke's generalized law

$$\begin{aligned} \sigma_1 - \nu(\sigma_2 + \sigma_3) &= \pm \sigma_0, \\ \sigma_2 - \nu(\sigma_1 + \sigma_3) &= \pm \sigma_0, \\ \sigma_3 - \nu(\sigma_1 + \sigma_2) &= \pm \sigma_0 \end{aligned} \tag{3}$$

are the equations defining the condition of yielding. According to this theory, if $\sigma_3 = 0$ or for plane stress with Poisson's ratio 0.30, an element carrying two principal tensile stresses of equal magnitude at right angles to each other could support 43 per cent. greater stress than for uniaxial stress before yielding would begin. As will be seen later on this reenforcing effect is not realized under actual tests.

Maximum Shear Theory.—Originally suggested by Coulomb, the maximum shearing stress then defines yielding under this condition. Since in general there are three different principal shearing stresses, this theory may be expressed by

$$\begin{aligned} \sigma_1 - \sigma_2 &= \pm \sigma_0, \\ \sigma_2 - \sigma_3 &= \pm \sigma_0, \\ \sigma_3 - \sigma_1 &= \pm \sigma_0. \end{aligned} \tag{4}$$

The maximum value in this case of course defines yielding.

Total Strain Energy Theory—Beltrami and Haigh suggested that the total strain energy under bi- or tri-axial stress should be the same as under uniaxial stress for beginning yielding. It is known that the total strain energy for 3-dimensional stress may be formulated as

$$V = \tfrac{1}{2}(\sigma_1\epsilon_1 + \sigma_2\epsilon_2 + \sigma_3\epsilon_3). \tag{5}$$

If the expressions for the principal strains as determined from Hooke's generalized law be substituted in this later equation, the total strain energy theory becomes

$$\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - 2\nu(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1) = \sigma_0^2. \tag{6}$$

Constant Energy of Distortion Theory.—This theory, the most recently developed of those considered here, was developed independently by von Mises, Huber, and Hencky. If the strain energy of volume change be subtracted from the total strain energy given in equation (5), there remains the strain energy due to distortion of the material. If this is the same for all conditions of stress, this theory becomes

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2\sigma_0^2. \tag{7}$$

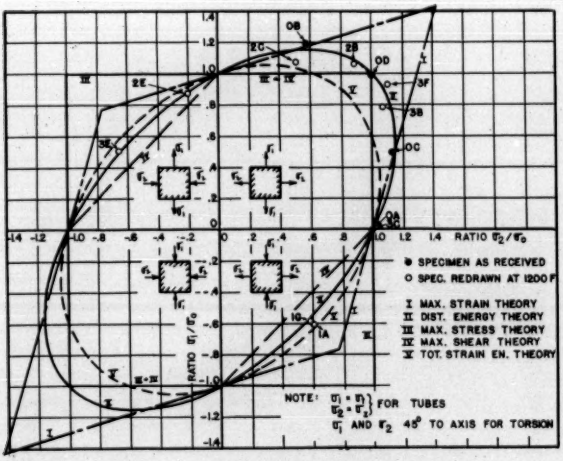
For the thin-walled tubes tested in these experiments, the three principal stresses σ_1, σ_2, σ_3 become σ_t, σ_z and σ_r or the stresses in the tangential, axial and radial directions respectively. These various theories are plotted non-dimensionally in Fig. 16 where $\nu = 0.30$. The experimental values obtained are also plotted in this figure. In determining the principal stress values to use in the above strength theories, the effect of work hardening in the material was taken into account as was originally done by Lode such that those principal stress values were selected for the same plastic ϵ_z or plastic axial strain which was used to determine σ_0. In certain instances where ϵ_z could not be used, ϵ_t was substituted as indicated on the diagram. For torsion, however, which is represented by test pieces 1*A* and 1*G*, the octahedral shearing strain γ_n was substituted where

$$\gamma_n = \tfrac{2}{3}\sqrt{(\epsilon_1 - \epsilon_2)^2 + (\epsilon_2 - \epsilon_3)^2 + (\epsilon_3 - \epsilon_1)^2}. \tag{8}$$

In this matter case γ_n was computed corresponding to a definite value of M_t as given by Fig. 14. Also corresponding

to this same value of M_t the shearing stress in the outside fiber τ_a was calculated by equation (1). This latter value is equal to $\sigma_1 = -\sigma_2$. Hence the principal stresses corresponding to a definite γ_n are now known. The value of σ_0 in simple tension was then determined for this same γ_n making use of equation (8). The ratios of $\frac{\sigma_1}{\sigma_0}$ and $\frac{\sigma_2}{\sigma_0}$ were then plotted in Fig. 16.

FIG. 16.


RATIO σ_2/σ_0
RATIO σ_1/σ_0
SPECIMEN AS RECEIVED
SPEC. REDRAWN AT 1200°F
I MAX. STRAIN THEORY
II DIST. ENERGY THEORY
III MAX. STRESS THEORY
IV MAX. SHEAR THEORY
V TOT. STRAIN EN. THEORY
NOTE: $\sigma_1 = \sigma_3$, $\sigma_2 = \sigma_4$ FOR TUBES
σ_1 AND σ_2 45° TO AXIS FOR TORSION

Comparison of test results with various strength theories.

Note.—Plastic strains used corresponding to points on diagram.

	Test Piece No.	ϵ_a in./in.	ϵ_t in./in.	γ_n in./in.
New Tests	*OA*	0.002		
	2*C*		.002	
	2*E*		.002	
	3*E*	−0.002	+.002	
	1*A*			0.00223
	1*G*			0.00223

It will be noted that for all of the stress ratios tested which comprise more than one half the diagram the constant energy of distortion theory checks the most favorably with the test results.

SUMMARY.

Combined stress tests are described in which thin walled tubes of a nickel-chrome-molybdenum steel are subjected to either combined axial tension and internal pressure or combined axial compression and internal pressure. Torsion tests on solid bars of this same material were also made. The experimental results agreed the most favorably with the constant energy of distortion theory of strength.

ACKNOWLEDGMENT.

These tests were made in the laboratories of the Department of Mechanical Engineering of the Massachusetts Institute of Technology and the authors wish to acknowledge the interest and support given to the work by Doctors Compton and Bush of the Administration and by Dr. Hunsaker, Head of the Department of Mechanical Engineering. Their thanks are also extended to Mr. P. R. Shepler for valuable assistance in making the tests, to the Charlestown Navy Yard for assistance in preparing the test specimens, and to Messrs. F. W. Perkins and H. Johnson of the Institute for their careful construction of the apparatus used.

BIBLIOGRAPHY.

1. A. NÁDAI, "Plasticity," 1931, pp. 59–74. McGraw-Hill Book Company, Inc., New York.
2. W. LODE, "Der Einfluss der mittleren Hamptspannung auf das Fliessen der Metalle," Dissertation, University of Göttingen, Germany, 1928.
3. A. NÁDAI, "Theories of Strength," *Transactions of the A. S. M. E.*, Vol. 1, July-September, 1933, pp. 111–123.
4. G. I. TAYLOR AND H. QUINNEY, "The Plastic Distortion of Metals," *Philosophical Transactions of the Royal Society, London*, Vol. 230, November 1931, pp. 323–362.
5. M. RÔS AND A. EICHINGER, "Versuche zur Klärung der Frage der Bruchgefahr," Diskussions-bericht Number 34, Materialprüfungsanstalt an der E. T. H., Zurich, 1929.
6. H. J. GOUGH AND H. V. POLLARD, "The Strength of Metals Under Combined Alternating Stresses," *Proceedings of the Institution of Mechanical Engineers*, Great Britain, Vol. 131, 1935, pp. 3–103.
7. J. M. LESSELLS AND C. W. MACGREGOR, "Certain Phases of the Combined Stress Problem," *Proceedings of the Fifth International Congress of Applied Mechanics*, Cambridge, Massachusetts, September 1938, pp. 201–206.
8. A. NÁDAI, "Plasticity," 1931, p. 128, McGraw-Hill Book Company, Inc., New York.

Chemical Plant Develops New Coal Storage Plan.—(*Gas Age*, Vol. 85, No. 8.) A thousand tons of coal a day is the requirement of the Dow Chemical Company. For three years now, this Midland Michigan company's unique and revolutionary coal-handling and storage methods have been attracting nation-wide attention. In the past, coal was dumped directly from lake boats. Slack was piled loosely just as it fell, allowing free entry to air. In such a pile, natural classification soon caused a separation of fine and coarse particles, the former being more firmly compacted than the larger pieces. When a second load was piled on the first, the same thing happened; and repeated with each succeeding load. An oblique stratification was caused by this method. Between each fine layer lies a coarse one, which being loosely compacted, constitutes a sort of flue or series of flues. In case of fire these function similar to chimneys. The warm air rising through them allows cold air to filter through the coal at the bottom of the pile and feed the flames. Coal is now stored in horizontal rather than oblique strata. There is little need to fear spontaneous combustion, since coal is packed so tightly that little of the fire-breeding oxygen can filter in. So far, no rises in temperature have been noted, even after 18 months of continuous storage. For loading, transporting and compacting, one caterpillar tractor hauling a carry-all and shoving a bulldozer is used. This unit handles an average of 130 tons per hour. A costly item in many coal handling routines is the freezing of coal to the sides of hopper-bottom railroad cars. Dow's remedy is to spray the insides of cars during cold weather with a solution of "Dowflake" Calcium Chloride, non-freezing even at temperatures well below zero Fahrenheit.

R. H. O.

THE CINEMA INTEGRAPH.

A MACHINE FOR EVALUATING A PARAMETRIC PRODUCT INTEGRAL.

BY

H. L. HAZEN, Sc.D., AND G. S. BROWN, Sc.D.,

Massachusetts Institute of Technology,

WITH AN APPENDIX BY

W. R. HEDEMAN, JR., Sc.D.,

National Geophysical Company, Texas.

(*Continued from July issue.*)

ACCURACY, PRECISION AND LIMITATIONS ON USE.

For the majority of problems the magnitude of the solution is accurate to within approximately one per cent. of full scale, where full scale is that positive or negative magnitude which would be indicated if the balance shutter closed completely or opened completely from its position of zero integral. The precision of the machine is considerably better than one per cent. throughout periods of time usually required for a solution.

Errors occur in the solution owing to (1), the human element involved in the procedure, (2), the physical imperfections in the component units of the machine, and (3), the inherent inability of the machine to evaluate the integral as required mathematically because of limitations imposed by its design. The errors belonging to classification (1) above arise because of:

(a) Inaccurate plotting of the curves of the functions and inaccurate following of the curves by the index point of the film exposer when exposing the films.
(b) Lack of care or skill when processing the film, thus causing the transparency of the unexposed areas to be non-uniform.
(c) Unequal shrinkage of the films for the various apertures during the period between processing and use.
(d) Halation at the boundary between the transparent and opaque regions of the film.

(e) Inaccurate location of the films in the apertures.
(f) Operation of the machine with an unnecessarily small maximum displacement of the balance shutter.

The errors belonging to classification (2) above arise because of:

(g) Non-uniform radiation characteristics of the line-filament lamp.
(h) Non-uniform transmissions characteristics of the mirrors, lens, integrating spheres, and balance shutter in the optical system.

The errors belonging to classification (3) above arise because of:

(i) Non-uniform illumination on the surface of the rear aperture for a given transparent ordinate on the front aperture, resulting from the finite ratio of the aperture height to the separation of apertures. This ratio should ideally be zero.
(j) Finiteness of the diameter of the filament of the line-source.
(k) Diffraction of the light transmitted past the vertical or near vertical edges of the opaque regions of the film in the front aperture.
(l) Evaluating an integral with an infinite upper limit as one with a fixed upper limit.
(m) Being unable to represent infinite ordinates on the films.

The errors belonging to classification (1) above, that is a–f inclusive, are made small and usually negligible by the use of care and skill when preparing the plots, processing the films and operating the machine. The errors of classification (2), that is g–h above, have been made small by careful workmanship in the construction of the component units. The errors belonging to classification (3) however, that is i–m above, are a function of the design dimensions of the machine and in certain problems impose definite limitations on the machine accuracy and on its scope. A brief discussion of the means adopted to minimize these latter errors will now be given.

V.2
194

The error resulting from the non-uniform illumination on the rear aperture, item i above, is negligible in most problems for the dimensions of aperture height and separation used in the design, provided the sides of the wedges used in the film exposer, Figs. 7*a* and 7*b*, are given the slight correction mentioned in the preceding section. The errors resulting from the finiteness of the filament diameter, item j, and the diffraction of the light transmitted at nearly vertical edges of the opaque zones on the front aperture, item k, are not so readily made negligible. The obvious modification of the design to reduce one increases the other since reducing the filament-diameter error requires, for a given diameter, increasing the spacing between apertures, whereas reducing the diffraction errors requires decreasing the spacing between apertures.[13] Fortunately an operating procedure is available which simultaneously reduces both errors; namely, always to prepare the films for use in the front apertures so that the absolute values of the maximum slope of the curves they represent do not exceed a given amount.

The magnitude of the slope permitted depends on the general shapes of the curves encountered in the particular problem. It is best determined on the basis of experience and frequently ranges around ten. The slope is reduced as the abscissa distance representing a given number of units of the variable x on the film is increased. Satisfying this requirement frequently extends the range of the variable of integration beyond the range of abscissa then represented by the length of the apertures, so that several frames on the film are required for the representation of each function. With such a procedure the value of the integral is then given not by a single number or a single curve, but (1) by the algebraic sum of the numbers representing the component solutions for each value of y if the kernel is of the form $f(x, y)$; or (2) by the

[13] This indicates that variable-density exposure would be superior to variable-ordinate exposure as here used, since the films could be used flat on top of one another. Variable-density exposure was not used merely because of the relative simplicity of the film-processing technique required for variable-ordinate exposure. The opportunity to extend the scope of the existing machine so that it could evaluate the integral of the product of four functions simply by using two variable-density films each placed face-to-face with one of the variable-ordinate films. should be noted.

addition of the separate curves for the component solutions, each as a function of y, if the kernel is of the form $f(y \pm x)$.

The error resulting from treating an integral with an infinite upper limit of integration as one with a finite fixed limit, is subject to satisfactory control by careful choice of the range of integration. The integral must converge at reasonable values of the upper limit if its solution by the machine is to be practical. Naturally, the abscissa range desired for the solution depends on the degree of convergence obtained as the upper limit of integration is increased. More specifically, if the value of one function be relatively large for large values of the variable x, the curves do not need to be extended to these large values if the value of the other function is so small that the *integral* of the product of the two functions between a limit say $x = x_1$ and $x =$ infinity, is negligible compared with the integral between the lower limit and $x = x_1$. For the majority of problems it is possible to estimate sufficiently accurately the maximum error introduced by the choice of a particular range of integration, and hence to select a suitable abscissa scale.

If, however, the desired integral has a finite value, its evaluation can be split into two parts, the first for ranges of limits approaching but not including the points at which infinities occur in the functions; the second for ranges including these infinities. The first part can be carried out directly by the machine. A satisfactory value can usually be obtained in the second part of the evaluation either by approximate formal methods, or by the machine using suitably altered scales.

An analysis of the processes involved in minimizing errors frequently indicates that the time for a solution is increased as the error is decreased. Frequently, the machine may be used to advantage for performing a rapid exploratory solution and giving results which, while not highly accurate, are valuable because they indicate the conditions for which the longer and more accurate solution should be undertaken by other means. A procedure that shows promise of becoming widely applicable is that of using the Cinema Integraph to perform rapidly the exploratory solutions, and then to use a more accurate machine such as a Differential Analyzer to

perform the final solution. Also, if the solution of a problem can be expressed as a known function plus a relatively small "difference integral," the machine method can frequently be used to advantage for the evaluation of the difference integral, and be the means for giving the whole solution with high order of accuracy.

The foregoing procedure, utilizing the Differential Analyzer to obtain a more accurate solution of an integral equation than one obtained by means of the Cinema Integraph, is illustrated in the first example in the appendix. In this illustrative solution there are three principal steps. First, an approximate solution is rapidly run off on the Cinema Integraph. Second, a more accurate integration, based on the approximate Cinema Integraph solution, is made on the Differential Analyzer. Third, a difference integral equation, based on the Differential Analyzer integration, is solved rapidly on the Cinema Integraph for the correction function needed to yield a solution which is more accurate than that given by the Cinema Integraph in the first step. In fact, the accuracy obtainable by this method is limited only by the accuracy of the Differential Analyzer integration.

TYPICAL APPLICATIONS.

Several fields of analysis in engineering and science wherein parametric product integrals are involved, are discussed by Gray in the original paper [14] on the Photoelectric Integraph. In particular, Gray treats the application of his integraph to the evaluation of integrals of the form encountered in the Fourier Transform,[15] in the superposition theorem [15] in the Poisson-type of integral equation, and in studies involving periodogram and correlation analyses.[16]

Because of the restricted scope of the Photoelectric Integraph its application to problems involving kernels of the form $f(x, y)$ was somewhat impractical. Hence, where this form of kernel was involved as for example in the Fourier Transform, the kernel was changed to the form $F(y \pm x)$ by an appropri-

[14] Gray, T. S., loc. cit.

[15] Bush, V.: "Operational Circuit Analysis," John Wiley and Sons, New York, 1929.

[16] Wiener, N.: "Generalized Harmonic Analysis," *Acta Mathematica*, **55**, 1930.

ate change of variable. It can be shown [17] that many kernels of the form $f(x, y)$ can be converted to the form $F(Y \pm X)$ in which Y and X are functions respectively of y and x only. The criterion to be satisfied in order that the conversion be possible is that the ratio $\frac{\partial f}{\partial x} \Big/ \frac{\partial f}{\partial y}$ be reducible to an expression involving a function of x only, say $\varphi(x)$, divided by a function of y only, say $\theta(y)$. When this criterion is satisfied the new variable X is given by

$$X = \int \varphi(x)dx, \tag{14}$$

and the new variable Y, by

$$Y = \int \theta(y)dy. \tag{15}$$

Sometimes, however, the conversion is not useful even when the expression for the change of variable can be found, because the resulting functions are poorly adapted for use in graphs.

Because the Cinema Integraph affords a practical means for handling the integral with the kernel $f(x, y)$ it is of interest to cite a few instances of its occurrence. Perhaps the expansion of a function in a series of orthogonal or bi-orthogonal functions furnishes the most familiar example, the best known of such functions probably being the Fourier series. When once the films for $\sin nx$ and $\cos nx$ are prepared it is a simple matter to expand any function, say $g(x)$, into its Fourier series, since it is only necessary to prepare the film for this function, adjust the machine and allow it to record the numerical values of the sine and cosine coefficients. In the same classification are included the expansion of functions in terms of Legendre, Laguerre, Hermitian or Tschebyscheff Polynomials.[18]

Quite generally problems involving the principles of potential theory can be formulated in terms of integral

[17] The proof of the theorem has been demonstrated to the authors in a private communication from Claude E. Shannon, Department of Mathematics, Massachusetts Institute of Technology.

[18] Wiener, N.: "Hermitian Polynomials and Fourier Analysis," *Jl. of Math. and Physics*, 8, 1929.

equations. Potential theory is applicable to the electric and magnetic fields associated with charged or magnetized bodies, to the flow and pressure fields of hydrodynamics and aerodynamics associated with the flow of fluids around solid bodies,[19] to illumination, and to elasticity. Two classical examples that may be cited are the Neumann Problem[20] and the Dirichlet Problem.[20] In the former problem the normal component of the gradient is defined along a closed contour and it is desired to find the potential V throughout the interior or exterior region. The problem is set up in terms of a single layer of charge and leads to an integral equation of the form

$$f(p) = \psi(p) - \lambda \int_c \psi(q)K(q, p)dq, \tag{16}$$

in which p and q are variables ranging over the contour, $f(p)$ is the known gradient, $\psi(p)$ is the unknown charge density, $K(q, p)$ is the kernel and a function only of the shape of the contour, and λ has the value $\pm$ 1 depending on whether the problem is for the internal or external region. Similarly, the Dirichlet Problem concerns the finding of a double layer of charge that will yield a given potential distribution. This problem leads to an integral equation of the form

$$F(p) = \varphi(p) - \lambda \int_c \varphi(q)K(q, p)dq, \tag{17}$$

where $F(p)$ is the known potential distribution, $\varphi(p)$ is the unknown double-layer distribution, the variables, the kernel and λ having the same significance as in Eq. (16).

The Eqs. (16) and (17) are integral equations of the second kind, Fredholm type. It can also be shown that by means of a continuous distribution of sources and sinks, or of doublets, along an axis of symmetry of a surface it may be possible to represent a prescribed potential function on this surface. Smith[21] has applied a source-sink distribution and

[19] Lamb, Horace: "Hydrodynamics," Cambridge University Press, 1932.

[20] Riemann, B.: "Die Differential und Integralgleichungen der Mechanik und Physik," Vol. I, Braunschweig, 1930.

[21] Smith, R. H.: "Aerodynamic Theory and Test of Strut Forms," *N. A. C. A. Annual Rep.*, 15, No. 311, pp. 125–148; No. 335, pp. 721–759; 1929.

Föttinger [22] a doublet distribution to such analyses in aerodynamics. These analyses lead to the formulation of the expression for the flux or stream function, which is orthogonal to the velocity or potential function, and yield an integral equation of the form

$$F(x) = k \int_a^b \varphi(s) N(x, s) ds, \tag{18}$$

where the kernel $N(x, s)$ is a known function of the body shape, $F(x)$ is the known stream function, and $\varphi(s)$ is an unknown source-sink or doublet distribution.

Because of the excessive amount of labor involved in the evaluation of integral equations only those problems that are readily treated formally have been studied with much thoroughness. The Cinema Integraph is equipped to handle integrals of the form of Eqs. (16) and (17) fairly directly. For certain forms of the functions involved in Eq. (18), the machine is also capable of giving a solution in a fairly direct manner.

Since the completion of the Cinema Integraph considerable unpublished work on the study of the forces on ship hulls [23] having various forms of immersion has been performed. The scope of the machine for analyses of this kind is readily demonstrated by a brief description of the procedure for determining the righting moments about a longitudinal axis for a hull in still water.

Consider the ship hull as divided into n equally-spaced transverse sections, the number of sections being chosen sufficiently large so that if each section is assumed to be of uniform cross section the error in the representation is arbitrarily small. Referring now to Fig. 8 let the longitudinal axis pass through the center of gravity of the vessel, and let θ be the angle of heel, n be the number of the hull section

[22] Föttinger, H.: "Die Entwicklung der 'Vektorintegratoren' zur Maschinellen Lösung von Potential und Wirbelproblemen," *Zeit. für Tech. Phys.*, 9, 26–39, 1928.

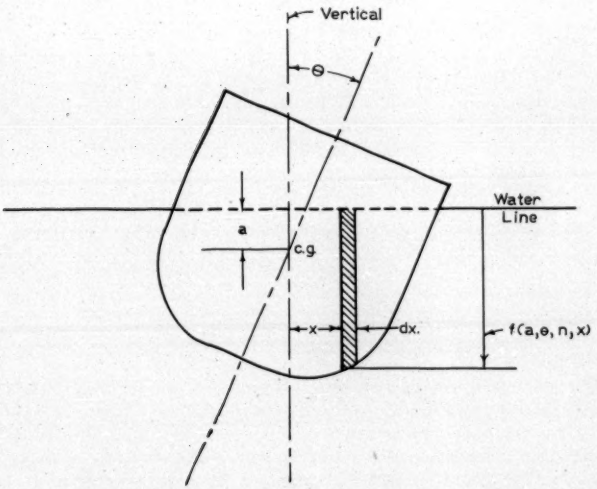
[23] Originally suggested by Dr. V. Bush. A paper entitled "Calculation of Motion and Stresses of a Pitching and Heaving Ship" by H. L. Hazen and P. T. Nims has been accepted for publication by The Society of Naval Architects and Marine Engineers.

measured along the longitudinal axis, a the immersion of the center of gravity below the water line, and x the distance measured along a horizontal transverse axis from the center of gravity.

The righting moment on a hull is given by the expression

$$F(a, \theta) = \sum_{\text{bow}}^{\text{stern}} \int_{\text{width of section}} f(a, \theta, n, x)x\,dx, \qquad (19)$$

FIG. 8.



Transverse section of ship hull for demonstrating calculation of rolling moment.

where

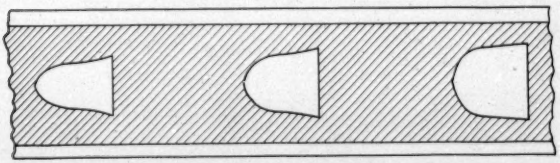
$F(a, \theta)$ = the righting moment as a function of immersion a, and heel angle θ,

$f(a, \theta, n, x)$ = displacement of hull element at x for hull immersion a, heel angle θ, section n.

The function $f(a, \theta, n, x)$ is transferred into the machine by preparing a film on each frame of which the transparent area represents a transverse hull section, the longitudinal ship axis

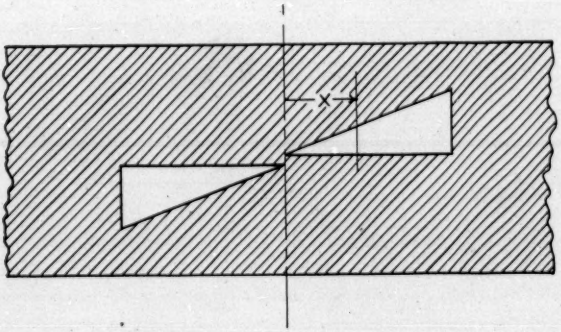
containing the center of gravity of the hull being in the geometric center of each frame on the film. A portion of a typical film is shown in Fig. 9*a* which is prepared for the aperture A_1. The parameter θ is introduced by a rotational displacement of this aperture about its geometric center as provided for in the design of the machine. The water-line

FIG. 9*a*.



Drawing of film for ship hull showing three transverse sections of hull.

FIG. 9*b*.



Drawing of film for $g(x) = x$, used in rolling moment calculation.

boundary for $f(a, \theta, n, x)$ is introduced by the simple expedient of placing a mask immediately in front of the film in the aperture A_1 so positioned that its bottom edge is at the water-line level, and that it intercepts all light above the water-line and none below the water-line. The factor x is transferred into the machine by a film prepared for aperture A_2 as shown in Fig. 9*b*. This film serves to multiply the buoyant force

on each longitudinal vertical element of the hull by its horizontal transverse distance from the center of gravity of the vessel, thus giving the rolling moment of this force. The components of light transmitted by the aperture A_2 above and below the abscissa axis represent respectively the positive and negative contributions to the righting moment. Hence, for each hull section represented by the frame of the film in aperture A_1 the machine indicates the net righting moment for the immersion and angle of heel. Obviously for the normal symmetrical hull shape, the net righting moment is zero when the vessel is on an even keel regardless of the depth of immersion.

By suitable modifications of the foregoing procedure for the investigation of rolling moments, the buoyant forces and pitching moments acting on a hull in waves can be determined including the effect of the "Smith Correction" or correction to the buoyant force of water resulting from the acceleration of the water particles in a wave. Given the means for rapidly calculating these forces and moments, the step-by-step integration of the differential equations of motion of the hull becomes practicable. This in turn yields the necessary data for the determination of shearing and bending stresses in the hull under the dynamic conditions of motion in a seaway.[23]

This list of problems involving parametric product integrals is merely suggestive but serves to indicate some of the fields in which the Cinema Integraph can be useful. The work already completed on typical specific problems in several of these fields by way of exploration has shown that the machine gives solutions that are wholly satisfactory, usually in a small fraction of the time required by the alternative methods.

APPENDIX. SOLUTIONS OF ILLUSTRATIVE PROBLEMS.

Contributed by W. R. HEDEMAN, JR.

This appendix illustrates the procedures involved in solving two examples. The first example concerns the determination of the current-density distribution within a conductor carrying an alternating current. This particular example is presented for three main reasons: first, because it demonstrates the technique of machine solution when the kernel has the general

form $f(x, y)$; second, because it illustrates the procedure for combining the speed of the Cinema Integraph with the accuracy of formal or precision machine methods to yield an accurate result rapidly; and third, because the accuracy with which the machine can handle the problem is readily determined by comparison of its result with the known accurate solution of the problem.

The second example gives the solution of the replacement problem as formulated early in this paper. Here the kernel is of the form $f(y - x)$.

EXAMPLE 1. CURRENT DENSITY DISTRIBUTION.

As shown by Manneback [24] the current density in an isolated non-magnetic solid, circular, cylindrical conductor can be described by the equation:

$$i(r) = i(0) + \alpha^2 \int_0^r \rho \ln \frac{r}{\rho} i(\rho) d\rho, \qquad (20)$$

in which

$i(r)$ = the complex current density at distance r cm. from the center of the conductor (see Fig. 10),

$i(0)$ = the complex current density at the center of the conductor,

$\alpha^2 = j \frac{4\pi\omega}{\sigma}$,

ω = the angular frequency in radians per second of the current in the conductor,

σ = the resistivity of the conductor,

ρ = the variable of integration,

$j = \sqrt{-1}$.

In this problem the function $i(r)$ is unknown, hence Eq. (20) is an integral equation of the second kind, Volterra type.[25] Since the coefficient α^2 is a pure imaginary quantity, Eq. (20) can be considered as being the combination of two component equations if $i(r)$ is separated into its real and imaginary

[24] Manneback, C.: "An Integral Equation for Skin Effect in Parallel Conductors," *Jl. of Math. and Physics*, 1, pp. 123–146, April, 1922.

[25] Lovitt, W. V.: "Linear Integral Equations," McGraw-Hill, New York, 1924.

components:

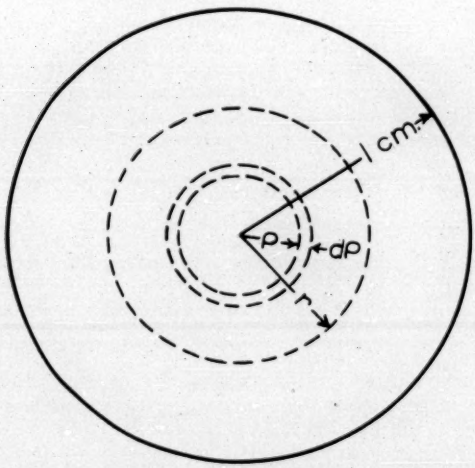
$$i(r) = i_R(r) + ji_I(r), \tag{21}$$

in which

$i_R(r)$ = the real component of current density,
$i_I(r)$ = the imaginary component of current density.

Further, if the current density at the center of the conductor

FIG. 10.



Cross section of cylindrical conductor for current density distribution example.

is arbitrarily set equal to unity,

$$i_R(r) = 1 - \alpha_1^2 \int_0^r \rho \ln \frac{r}{\rho} i_I(\rho) d\rho, \tag{22a}$$

$$i_I(r) = \alpha_1^2 \int_0^r \rho \ln \frac{r}{\rho} i_R(\rho) d\rho, \tag{22b}$$

where

$$\alpha_1^2 = -j\alpha^2 = \frac{4\pi\omega}{\sigma}. \tag{23}$$

The system of Eqs. (22*a*) and (22*b*) is readily solved by the method of successive approximations.[26] Briefly, the procedure here is to consider that unity is the first approximation to the solution for the real current density $i_R(r)$. This approximation can be put into Eq. (22*b*), and a first approximation for the imaginary current density, $i_I(r)$, computed by the direct evaluation of the integral. A second, and more nearly correct approximation to the real current density is now given by substituting the first approximation for the imaginary current density in the integrand of Eq. (22*a*) and evaluating the integral. The result of this computation can then be used in Eq. (22*b*) to compute the second approximation to the imaginary current density and so on. Mathematically, this process is convergent, and there is one, and only one solution to which the process can converge, and that is the correct solution. Computationally, machine errors limit the accuracy obtainable by this direct process.

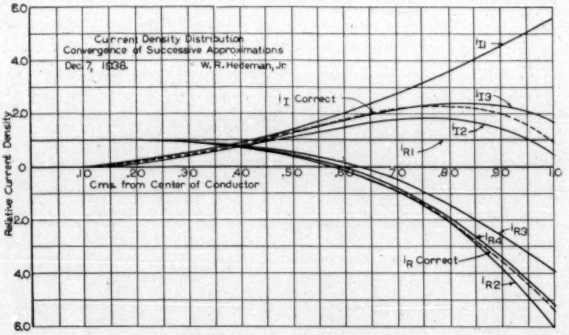
In Eqs. (22*a*) and (22*b*) the kernel, $\rho \ln \frac{r}{\rho}$, is of the stepping type $f(r, \rho)$ in which r is the parameter and ρ is the variable. The function $f(r, \rho)$ is plotted for the values of r desired, and from these plots the kernel film is prepared so that on each frame the unexposed area is the area beneath the curve for that particular value of r. On each frame the maximum value of abscissa is for $\rho = r$, as this is the upper limit of integration. Once prepared, this kernel film serves throughout the solution. As each step in the approximation to the solution is carried out it is necessary to make a new film which represents the approximation derived from the preceding computation. This does not involve an appreciable amount of time however, as the process of making single films is rapid.

The curves of Fig. 11 show the results obtained for several successive approximations to the real and imaginary current density distributions, and also show the correct solution to the problem. The approximations are denoted by i_{R1}, i_{R2}, i_{R3} and i_{I1}, i_{I2}, i_{I3}, the first approximation to the imaginary current density distribution being the result of a computation in which the first approximation to the real current density

[26] Lovitt, W. V.: loc. cit.

distribution was taken as unity. However, the second approximation to the real current density distribution is the result of using the first computed approximation to the imaginary current density distribution, as is stated in the outline of the process. Figure 12 shows the manner in which

FIG. 11.



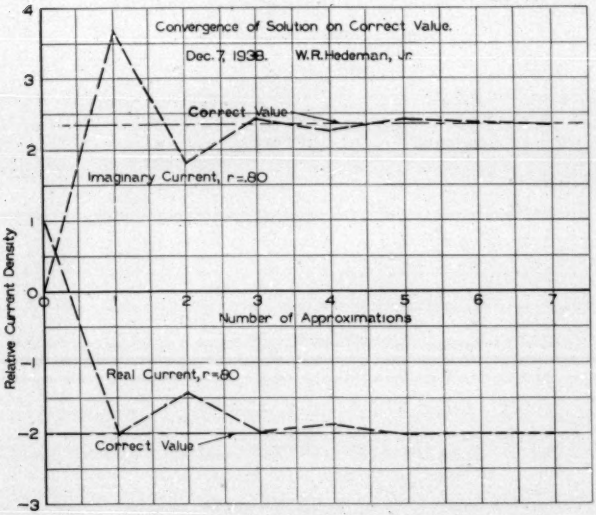
Results of current density distribution calculation. i_{I1}, i_{I2}, i_{I3} are first, second and third approximations to i_I, resp.; i_{R1}, i_{R2}, i_{R3}, i_{R4} are corresponding approximations to iR.

the machine result for $r = 0.8$ converges on the correct value.

The results for the eighth and last approximation are given in Table A, in which columns 2 and 3 show the values of real and imaginary components, i_{R8} and i_{I8}, of current density as a function of the radius r. The example applies to a conductor of 1 cm. radius for $\frac{\omega}{\sigma}$ equal to 0.580π radians per sec divided by abohms per cm. cube. Successive approximations in this problem were obtained at intervals of about one hour after the kernel film had been prepared. The time required to prepare the kernel film was about four hours. Columns 6 and 7 of the same table show the values of the formal solution $J_0(\alpha r)$, where J_0 is the Bessel function of the first kind and zeroth order. Tables of this function are given by Jahnke and Emde.

The maximum error appearing in the results given in columns 2 and 3 is seen to occur at the maximum radius of the conductor, where the magnitude of the complex error is approximately 0.34, or about 6 per cent. of the complex current magnitude, the error decreasing rapidly with radius. This large percentage error is primarily the result of taking the

FIG. 12.



Graph showing convergence of solution in current density distribution problem.

difference between two nearly equal numbers, a process which inherently magnifies errors. However, the error can be much reduced by the following method.

In general terms, the error is reduced by forming and solving a difference equation written in terms of the Cinema Integraph approximate solution $i_n(r)$, and a correction function $\Delta i(r)$ by which $i_n(r)$ differs from $i(r)$. Here $i_n(r)$ is the nth approximation to the solution for $i(r)$. This difference equation, which is also an integral equation, is then solved on

the Cinema Integraph for the correction function, which when added to the approximate solution $i_n(r)$ gives a much more accurate approximation to the correct solution.

More specifically, the procedure in the refinement process is as follows: First, a new function is formed substantially identical with, or incorporating any intuitive improvements upon $i_n(r)$, but to which are arbitrarily assigned more significant figures than $i_n(r)$ contains. Let this more precisely

TABLE A.

Radius.	Cinema Integraph Approximate Solution.		Combined Cinema Integraph Differential Analyzer Solution.		Bessel Function Solution.	
r.	i_{R8}.	i_{I8}.	i_R.	i_I.	i_{RB}.	i_{IB}.
0.0	1.000	0.000	1.000	0.000	1.000	0.000
0.1	0.994	0.052	0.999	0.058	0.999	0.057
0.2	0.980	0.222	0.988	0.229	0.987	0.229
0.3	0.926	0.512	0.936	0.511	0.934	0.511
0.4	0.796	0.898	0.795	0.891	0.792	0.895
0.5	0.518	1.355	0.498	1.347	0.495	1.350
0.6	−0.014	1.828	−0.031	1.819	−0.031	1.820
0.7	−0.860	2.218	−0.862	2.220	−0.861	2.204
0.8	−2.082	2.379	−2.055	2.343	−2.048	2.343
0.9	−3.582	2.033	−3.602	2.030	−3.592	2.015
1.0	−5.252	1.391	−5.420	0.929	−5.396	0.933

defined function be called $i_{np}(r)$. Then let the correction function $\Delta i(r)$ be defined by

$$\Delta i(r) \equiv i(r) - i_{np}(r). \tag{24}$$

Substituting $i(r)$ from Eq. (24) in Eq. (20) gives

$$i_{np}(r) + \Delta i(r) = i(0) + \alpha^2 \int_0^r \rho \ln \frac{r}{\rho} [i_{np}(\rho) + \Delta i(\rho)] d\rho, \tag{25}$$

whence by transposition, and splitting the integral into two separate integrals,

$$\Delta i(r) = i(0) - i_{np}(r) + \alpha^2 \int_0^r \rho \ln \frac{r}{\rho} i_{np}(\rho) d\rho + \alpha^2 \int_0^r \rho \ln \frac{r}{\rho} \Delta i(\rho) d\rho \tag{26}$$

or

$$\Delta i(r) = a(r) + \alpha^2 \int_0^r \rho \ln \frac{r}{\rho} \Delta i(\rho) d\rho, \tag{27}$$

in which

$$a(r) \equiv i(0) - i_{np}(r) + \alpha^2 \int_0^r \rho \ln \frac{r}{\rho} i_{np}(\rho) d\rho. \tag{28}$$

It is of interest to note that the expression for $a(r) + i_{np}(r)$ is actually the $(n + 1)$ approximation as can be seen by a comparison of Eq. 28 with Eq. 20.

Eq. (27) is an integral equation from which the correction function $\Delta i(r)$ is determined. The more accurate solution of the original integral Eq. (20) is then given by

$$i(r) = i_{np}(r) + \Delta i(r). \tag{29}$$

A detailed consideration of this correction process shows certain precautions that must be observed if the best accuracy is to be obtained. For example, the accuracy of $i(r)$ as obtained from Eq. (29) depends only on the accuracy with which $\Delta i(r)$ can be determined provided $i_{np}(r)$ is initially defined with sufficient precision. Further, if additional applications of the difference-equation process are considered, it will be found that the ultimate limit upon accuracy of $i(r)$ is fixed by the accuracy with which the integral in Eq. (28) can be calculated.

In this example the Differential Analyzer was used for the integration in Eq. (28), whereas the Cinema Integraph was used in solving Eq. (27). The first approximation $\Delta i_1(r)$ to $\Delta i(r)$, given by

$$\Delta i_1(r) = a(r) - \alpha^2 \int_0^r \rho \ln \frac{r}{\rho} a(\rho) d\rho, \tag{30}$$

showed that further approximations would yield no additional accuracy, since the integral contributed only a small correction to $a(r)$. Columns 4 and 5 of Table A give the real and imaginary components of $i(r)$ as approximated by

$$i(r) \cong i_{np}(r) + \Delta i_1(r). \tag{31}$$

Values of the functions are tabulated only for values of r at intervals of 0.10, though computations were carried out for

values spaced at intervals of 0.025. With one exception, not shown in the table, all of the errors are under one per cent., and few exceed a few tenths of one per cent.

The method here illustrated, whereby the rapid, moderately precise Cinema Integraph is used for the large number of integrations (of the order of 700 in this example) involved in solving an integral equation and the more precise but much slower Differential Analyzer is used for one set of integrations to establish a precise difference equation which in turn is solved for a final correction function on the Cinema Integraph, is a method which undoubtedly has wide applicability in the solution of integral equations. By this procedure one obtains nearly the speed of the Cinema Integraph combined with the accuracy of the Differential Analyzer.

EXAMPLE 2. REPLACEMENT PROBLEM.

The solution of the replacement problem outlined in the early part of the paper imposes severe requirements of accuracy on the Cinema Integraph. As there stated, the problem is: Given the expectancy of life of a group of objects and the number of these objects desired in service as a function of time, what then is the rate at which these objects must be replaced, that is, added to or subtracted from, as a function of time? This problem is one of considerable interest for, in addition to the electric lamps used for the demonstration above, the objects may be freight cars, automobiles, machine tools,[27] or even human beings. Because of the broad scope of the method of analysis, the number of objects desired in service can be varied in any arbitrary manner; for example, to follow business activity or any other index. Because of certain important aspects of this problem it is of interest to discuss briefly certain properties of the functions involved before giving the solution.

The function $\sigma(t)$; that is, the reciprocal kernel for a given $S'(t)$, is obtained by solving Eq. (6), which with slight rearrangement is:

$$\sigma(t) = -S'(t) - \int_0^t \sigma(T) - S'(t\ T)dT. \qquad (6)$$

[27] Kurtz, E. B.: "Life Expectancy of Physical Property," Ronald Press, New York, 1930.

This is a linear integral equation of the second kind, Poisson type. Now suppose that it is desired to find the replacement function that would maintain an initial number of objects at a constant level, and for simplicity consider this number to be unity. Let the replacement function for this particular condition be $\rho(t)$. Eq. (2) can then be written as:

$$1 = S(t) + \int_0^t \rho(T)S(t - T)dT. \tag{32}$$

Differentiating with respect to time as before gives:

$$0 = S'(t) + S(0)\rho(T) + \int_0^t \rho(T)S'(t - T)dT, \tag{33}$$

but since $S(0)$ is taken equal to unity:

$$S'(t) + \rho(t) = -\int_0^t \rho(T)S'(t - T)dT. \tag{34}$$

A comparison of Eq. (6) with Eq. (34) shows that the function $\rho(t)$ must be identically equal to the function $\sigma(t)$. Hence the reciprocal kernel is, in effect, that replacement function which will maintain an initial unit population of new objects at the same level all of the time.

The solution given below is for a given number of human beings all born at time zero, their survival rate being derived from the standard mortality table for white females in the United States.[28] It was assumed that the initial number was to be maintained constant. Therefore the reciprocal kernel $\sigma(t)$ of Eq. (6) becomes the replacement-rate function. The procedure used to solve Eq. (6) was the so-called "Neumann" method,[29] wherein the function $\sigma(t)$ is represented as a series of the form:

$$\sigma(t) = K_0(t) + K_1(t) + K_2(t) \cdots K_n(t) \cdots, \tag{35}$$

where:

$$K_0(t) = S'(t), \tag{36}$$

$$K_1(t) = \int_0^t K_0(T)S'(t - T)dT, \tag{37}$$

$$= \int_0^t S'(T)S'(t - T)dT, \tag{37a}$$

[28] Dublin, L. I. and Lotka, A. J.: "Length of Life," Ronald Press, New York, 1936.

[29] Lovitt, W. V., loc. cit.

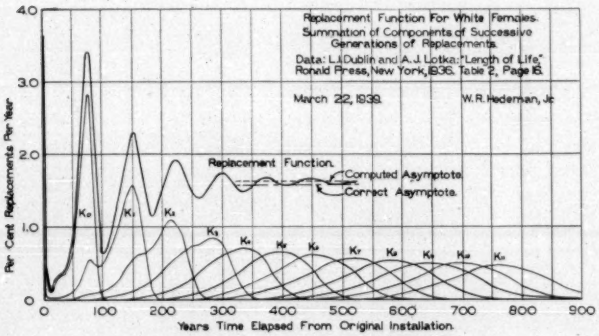
$$K_2(t) = \int_0^t K_1(T)S'(t - T)dT, \tag{38}$$

$$K_n(t) = \int_0^t K_{n-1}(T)S'(t - T)dT. \tag{39}$$

Plots of the functions $K_0(t)$, $K_1(t) \cdots K_8(t)$ as given by the Cinema Integraph together with the resulting plot of $\sigma(t)$ are shown in Fig. 13.

The solution of this problem using the Neumann series is a process requiring a high degree of accuracy on the part of the

FIG. 13.


Replacement Function For White Females.
Summation of Components of Successive Generations of Replacements.
Data: L.I.Dublin and A.J. Lotka: "Length of Life" Ronald Press, New York, 1936. Table 2, Page 18.
March 22, 1939.
W.R. Hedeman, Jr.
Replacement Function.
Computed Asymptote.
Correct Asymptote.
Per Cent Replacements Per Year
Years Time Elapsed From Original Installation.

Solution of illustrative replacement problem.

machine and care on the part of the operator. By the nature of the process any error originally present in plotting $S'(t)$ and transferring this function to film will appear in the function $K_1(t)$. This error will be cumulative in a geometric series in each successive step in the solution. Thus it is advisable to perform certain checks during the course of the solution. Fortunately, simple checks are available.

A running check on each step in the process can be obtained from the fact that:

$$\int_0^\infty K_n(t)dt \equiv 1, \tag{40}$$

which, as can be shown by an application of Dirichlet's formula,[30] is a mathematical property of the series solution for the reciprocal kernel $\sigma(t)$ of all replacement problems. This check can be used in each step of the process simply by means of planimeter integration of any result $K_n(t)$. The extent to which the machine solution for each function $K_n(t)$ satisfies Eq. (40) is shown by Table B.

TABLE B.
Replacement Problem.

No. of Substitution.	$\int_0^\infty K_n(t)dt$.	Error $\int_0^\infty K_n(t)dt - 1$.	Per Cent. Error.
0	1.000	0	0
1	0.995	−0.005	−0.5
2	1.010	+0.010	+1.0
3	1.040	+0.040	+4.0
4	1.020	+0.020	+2.0
5	0.996	−0.004	−0.4
6	1.010	+0.010	+1.0
7	1.020	+0.020	+2.0
8	1.014	+0.014	+1.4
9	1.047	+0.047	+4.7
10	1.058	+0.058	+5.8
11	0.991	−0.009	−0.9
12	1.012	+0.012	+1.2

A final independent check is also available, since the asymptotic value of $\sigma(t)$ for large values of t can be computed, and is given by:

$$\sigma(\infty) = \frac{1}{\int_0^\infty S(t)dt}. \qquad (41)$$

The numerical value of the asymptote given by Eq. (41) is indicated in Fig. 13. The difference between the asymptote given by the machine solution and the correct asymptote checks to within 2 per cent. after eight steps in the process in which errors tend to become cumulative. This indicates that the error in any one step must have been very small.

The curve of the particular $S'(t)$ function; that is, curve $K_0(t)$ of Fig. 13, involves a relatively steep slope at the origin.

[30] Bôcher, M.: "An Introduction to the Study of Integral Equations," Cambridge University Press, 2nd ed., 1926.

To avoid errors due to the diffraction of light in the optical system of the Cinema Integraph, this curve was spread over several frames when the curve of $K_1(t)$ was being evaluated. However, other than this precaution, no special methods of operation were necessary, it being only necessary to use reasonable care when preparing the curves and films to obtain accurate performance of the machine. The use of a running check to eliminate gross errors is advisable and helpful. The availability of a final check is desirable, but not essential.

The successive solutions for the $K_n(t)$ functions in this problem were obtained at intervals of about one hour when once the films for $S'(t)$ and $S'(t - T)$ had been prepared. The time required to obtain the complete $\sigma(t)$ function, including checks, was about 12 hours.

It will be noted that the method of solution of the equation for the skin effect involved successive approximations to the desired result whereas the solution for the replacement problem involved successive substitutions. In each problem the kernel film, once prepared, was used throughout the work. The procedure that proves to be most expedient with any problem depends almost wholly upon the particular form of the functions involved, and it should not be implied from these examples that the method of successive approximations works best with all kernels of the form $f(x, y)$ nor that the method of successive substitutions is best for problems with kernels of the form $f(y \pm x)$. Neither should it be implied that reciprocal kernels can be obtained only for kernels of the form $f(y \pm x)$.

ACKNOWLEDGMENTS.

The authors wish to acknowledge the leadership of Dr. Vannevar Bush during the period when the basic plans for this machine were being formulated, and to thank him for his unfailing interest and wise counsel so generously given ever since. They also wish to thank Mr. John H. Howard, Mr. Walter T. White, Mr. Paul T. Nims, and Mr. John C. Coombs for their valuable assistance with the experimental and developmental work, and also thank their many colleagues at the Massachusetts Institute of Technology for assistance they have received.

Trolley Bus on Stilts.—(*Transit Journal*, Vol. 84, No. 4.) Rapid transit service of a type different from any tried up to the present time has been proposed for Grand River Avenue, Detroit. The suggested plan contemplates the operation of trolley buses on a T-shaped elevated structure 16 ft. above the center of the street where there are now electric railway tracks. The maximum width of the upper part of the structure would be 25 ft. This would provide two 9½ ft. runways for the trolley buses, with a 6 ft. platform between them at stations. Between stations the space between the runways would be occupied by a catwalk. Supporting columns would be 6 ft. wide and would be located at 40 ft. intervals along the structure. The vehicles, themselves, designed to seat 52 passengers, would be 40 ft. long. Hence there would be no danger of overloading the structure by an unexpected concentration of vehicles. Current collection would be by means of shoes sliding on a pair of contact rails at the bottom of the runway. Except for these contact rails and two ribbons of concrete for the wheels of the vehicles, the bottoms of the runways would be open. This would facilitate drainage, prevent the accumulation of snow in winter, and avoid undue darkening of the vehicular roadway on the ground level. Stations would be located about 1/2 mile apart. Access from the sidewalk would be through a tunnel beneath the street, with an escalator to the station platform.

R. H. O.

THE BREAKING THEORY OF DETONATION.

BY

LEROY R. CARL.

PART II.

In the introduction to this paper the effort was mainly to show the failure of all present schemes or theories to bring order into the data on high explosives. In this portion of the paper it is the purpose to draw attention to the probability of a new theory. It is hoped that the new theory will, to a certain extent, clarify the nature of the phenomenon of detonation, in solid and liquid materials. It is also hoped that one point was sufficiently stressed in the introduction, i.e. that chemical composition, in the strictest sense, is of less importance than physical condition in determining the nature of the high explosive break-down or detonation. In the study of detonation, following, emphasis will be placed on sensitiveness. It has been stated, in the introduction that this characteristic of an explosive is the one without which it would not be an explosive. This statement may be clarified in this way; combinations of the elements having a stability factor (opposite of sensitiveness) which is too low cannot exist as compounds and those having a stability factor which is too high are not explosive compounds.

Before stating the basis of the new theory of detonation it is desired to present, in a very concise manner, a few phases of the newer theories of the structure of matter, which have a bearing on the proposed theory.

Sir William Bragg[1] has presented the nature of the solid state in common-place terms. On page 128 under the nature of crystals he says: "each molecule has a *definite shape* or outline, . . . The molecules join together as if there were definite points of attachment on each, and the junction implies that the proper points were brought together. The

[1] "Concerning the Nature of Things," 1925, Harper & Bros., N. Y. Italics are the writer's.

action between them is not usually to be compared to the general attraction between oppositely electrified bodies, but rather to the riveting together of two parts of a mechanical structure, such as two parts of an iron bridge." And he continues on page 129: "The consequence is that when the molecule contains many atoms, and is, therefore, probably of complicated structure and curious form, the solid that is formed by their union is of a lace-like formation in space. We may compare it to a bridge formed of iron struts and stays; which is a very empty structure, because each member is peculiar in form, generally long and narrow, and is attached to the neighboring members at definite points." And on page 130 "The infinite variety in the properties of the solid materials we find in the world is really the expression of the infinite variety of the ways in which the atoms and molecules can be tied together, and of the *strength of those ties*."

The same authority[2] putting his thought into other words says: "A crystal conforms so exactly to rules respecting its angular dimensions that it seems impossible to imagine its form to be merely the result of an average of tendencies. The forces of adjustment cannot therefore be thought of as a force between two points each representing one of the molecules. On the contrary, it is nearer the truth to think that the adjustment is made so as to bring together certain points on one molecule and certain points on the other. In considering, therefore, the binding of the individual molecules of a solid, the analogy of the electrostatic attraction of two charged spheres is imperfect, and should be replaced by that of two members of a girder structure adjusted until the rivets can be dropped into the holes brought into true alignment."

It is now desired to emphasize the fact that the structure of the molecule is also the structure of the crystal; which has been implied if not directly stated. In support of this view the words of Alexander[3] are quoted: "The X-ray spectrometer of Bragg reveals the fact that in crystals of sodium chloride, for instance, the atoms of sodium and of chlorine are regularly arranged in the space lattice so that each atom of sodium (on

[2] "Colloid Chemistry," Vol. 1, Alexander, Reinhold Publishing Co., N. Y., page 265.

[3] Ibid., page 12.

the interior) is surrounded by six atoms of chlorine, each 5.56 angstrom units from it. This means that the chlorine atoms are similarly situated, and gives, in cases like this, some color to the view of I. Langmuir that a crystal is in effect one large molecule."

In further support of the identity of the molecule and the crystal we have the words of Taylor:[4] "The distinction between regional orientation and a small crystal is that all the atoms in a small crystal may be looked upon as belonging to the same molecule, ..." And Nernst[5] says, "If we understand by molecules, aggregates of atoms which move about in space as a whole, we should have to consider *every* crystal a molecule, for the particles of a crystal are held together so firmly that one particle cannot move without the remainder moving with it." DuBridge has the following to say:[6] "Now the central idea of the new quantum theory of solids is simply that a crystalline solid body may be regarded as a single large molecule."

The molecule then has definite structure; a framework connected by valence forces which are directional and the crystal may for many considerations be treated as one large molecule.

It is now desired to call attention to some conclusions by researchers on the strength of the crystal and the nature of rupture. Joffe[7] says: "The tensile strength of single crystals is almost 500 times less than the calculated maximum for the cohesive forces and rupture occurs before an essential deviation from Hoope's law can be noticed." Joffe finds that rock salt crystals become plastic when immersed in hot water and exhibit strength up to 160 kg. per sq. mm. as compared to a strength of 0.5 kg. for the ordinary condition. He suggests as a possible hypothesis the existence of very small crevices in the surface which would cause the entire load to

[4] "Treatise on Physical Chemistry," Taylor, 1925, page 132, D. Van Nostrand Co., N. Y.

[5] "Theoretical Chemistry," 5th English Ed., 1923, page 324, Macmillan & Co. Ltd., London.

[6] *The Review of Scientific Instruments*, **9**, No. 1 (1938).

[7] "The Physics of Crystals," 1928, McGraw-Hill Book Co., N. Y., pages 59 and 63.

be exerted at a point instead of on the whole cross-section. Joffe continues as follows: "Dry pieces of rock salt are brittle under bending stresses. Under water they become flexible, which is an indication of the increase of the strength." This increase in strength is possibly caused by the fact that the fissures or crevices are dissolved away more rapidly than they form.

This condition is discussed by Adam [8] in these words: "Most solid substances have numerous small cracks in their surfaces. The first evidence for this comes from a comparison of the actual strength of crystals with that deduced from theoretical considerations. In the case of the ionic lattice of NaCl the theoretical strength calculated from consideration of the electrostatic forces between the ions of the order 200 kg. per sq. mm. Actually dry crystals of rock salt can be broken at 0.4 kg. per sq. mm. If strained in air the deformation of rock salt is very small, before it breaks."

A condition is discussed by Rideal [9] which has a bearing on the low strength values shown by crystals when he says: "Atoms in a crystal may in fact be regarded as surrounded by a field of force, and although there is but little residual attraction within the crystal, where each atom is situated symmetrically as regards the electrical forces of cohesion, the unsaturated character or the intensity of this field assumes large values in the space in juxtaposition to the crystal surface. The surface of a crystal is thus chemically *unsaturated* and the existence of a definite *surface energy* is due to the fact that the surface is *unsaturated*." The unsaturated condition of the surface is probably instrumental in the formation of the surface fissures or cracks and therefore unsaturation of the surface is the fundamental cause of the instability of all crystalline materials.

It is now desired to consider the subject of rupture from a slightly different angle. Bridgman [10] has the following to say on the subject, "Fracture occurs in a body when the ex-

[8] "The Physics and Chemistry of Surfaces," 2nd Ed., 1938, Oxford University Press, London, page 244.

[9] "Surface Chemistry," 2nd Ed., 1930, The University Press, Cambridge, page 169.

[10] *Journal of Applied Physics*, 9, page 519, August 1938.

ternal conditions are altered if all the atoms cannot find new positions, not far from the original positions, in which they will still be subject to zero net force on the average" * and "A complete theory of rupture would involve a formulation of all the conditions under which instabilities may arise. It is well known that the formulation of the conditions of stability is an extremely difficult mathematical problem. From the indifferent success of various attempts to formulate the conditions for such simple systems as regular crystal lattices it is to be expected that a general solution is at present beyond mathematical possibilities. The situation is further complicated by the probability that instabilities are almost always initiated at some imperfection in the structure, either internal, or on the surface, as shown by the success of various well known recent theories of rupture."

Bridgman [11] has shown that fracture or rupture sometimes occurs at the release of pressure, for instance, when a granular material is pressed in a cylinder it will be found to have divided into planes perpendicular to the applied stress, upon the release of the stress. A specimen in the shape of a rod when subjected to hydrostatic pressure on its curved surface with the ends free to move, was necked off and fractured in a manner nearly similar to that of a rod to which a stress had been applied parallel to its main axis. The same writer in speaking of a hard rubber ring broken by hydrostatic pressure says, "We have then, the paradox of a substance in which every strain is a shortening and every stress a compression, experiencing a clean tensile break. The break here is *against* the direction of the stress. It seems evident that it is the *distortions* in molecular arrangements which are effective, and the fact that every distance between molecules has been shortened *absolutely* at the moment of rupture is without pertinence." Such experiments show that breaking is not as simple a subject as at first it would appear. Breaking has been given insufficient study, in general, perhaps because it has been considered as an accident rather than as a universally significant phenomenon.

* Writer's Note: This applies only to the atoms in the interior; the atoms at the surface remain in an unstable or unsaturated condition.

[11] *Journal of Applied Physics*, **9**, pages 517–528, Aug. 1938.

We now have the picture of the crystal as held together by forces of great magnitude, but which may be broken, in fact, by forces of very small magnitude. We have seen, also, that breaking may take place by *distortions* which shorten all of the distances between the atoms or molecules. The unsaturated condition of the *endothermic* compounds will be treated later in this paper in more detail, especially their effect on the stability of the crystal.

Keeping this picture in mind let's turn our attention to elastic waves, which are usually spoken of as sound. First of all we need a comprehensive definition of sound. This can be supplied by Wood [12] who says, "In this respect sound may be considered as including that branch of mechanics which deals with *alternating or vibratory* motion" and farther on "The study of mechanical vibrations is closely analogous to that of alternating currents, the mathematical theory being almost identical when the members of certain pairs of fundamental qualities, e.g. inertia—inductance, stiffness—capacity, friction—resistance, are interchanged." And later still "The movement of any particle of the medium is, however, purely local, each particle making small *to-and-fro excursions* in a manner similar to that of the vibrating body itself" and "This local motion of the particles must be clearly distinguished from the motion of the disturbance which travels forward from layer to layer of the medium with an ever-increasing radius. It is the state of to-and-fro motion which advances, the medium as a whole, after the disturbance has passed, remaining in its initial position" and, "As we shall see, the velocity with which the wave travels is dependent on the *elasticity* and *density* of the medium." "This *wave*-velocity must not be confused with the variable *particle* velocity involved in the to-and-fro vibration." A statement by Jones [13] may add to the clearness of the subject: "When a compression is spreading out in all directions the inertia of each layer of air causes it to swing so far that it actually leaves *behind* it a region in which the air expands and becomes rarefied. Then with a *compression* in front of it and a rare-

[12] "A Textbook of Sound," Wood, pages 1 and 6, G. Bell & Sons Ltd., London.
[13] "Sound," A. T. Jones, 1937, D. Van Nostrand Co., N. Y., pages 20–21.

faction behind it the layer of air is brought to rest and may even be started *to move backwards*."

We will now quote Joffe to show the relation to classical physics and dynamics. On page 23 Joffe [14] says, "A stress applied to any ordinary solid body produces a strain continuously increasing with time. . . . On removal of the stress, the main part of the strain *disappears with the velocity of sound*. . . . Vibrations will die out more rapidly as a result of the elastic after-effect and the sound emitted becomes dull, etc." And on page 31 he continues, "They (elastic after-effect, elastic hysteresis, elastic fatigue, etc.) are due to the irregularities of heterogeneous bodies, to an exceeding of the elastic limit and to rupture inside small weak spaces within the body and to interactions between the crystalline grains."

We may summarize the nature of sound as follows:

1. A stress wave which travels through a body subjecting every portion to stresses, which produce strains, and mechanical distortions.

2. A wave which causes small to-and-fro movements of the medium.

3. The material after the passage of the wave remains in its initial position.

4. The velocity of the wave is dependent on the elasticity and density of the medium.

5. The rarefaction or extension of the material, causes the movement of the material, sometimes, to be in the direction opposite to the direction of the progress of the wave.

6. The removal of stresses from elastic materials allows the strains to disappear with the velocity of sound.

7. Materials which are not perfectly elastic have a tendency to damp out vibratory motion (sound). This damping effect is largely due to elastic after-effect, elastic hysteresis and plastic flow.

As has been stated or inferred, the crystal has definite shape because of directed valence forces which bind the atoms. We can now consider the condition of crystals in which there is an internal force, inherent in the structure of the crystal,

[14] "The Physics of Crystals," 1928, McGraw-Hill Book Co., N. Y., page 23 and 31.

which tends to displace the valence forces from their normal direction. This condition exists in endothermic or unsaturated compounds. This condition (endothermic or unsaturated) often causes such compounds to be initiators of detonation, and *is*, contrary to the opinions of some authorities * one of the most important characteristics determining their susceptibility to detonation.

A. Von Baeyer [15] in putting forth his theory of tension reasoned that the angle formed by the union of two carbon valencies was 109° 28′. That in the double bond arrangement there was a force acting to deflect the valence forces from their natural position. This condition is stated by Henrich [16] as follows: "The resistance offered by the valencies of carbon atoms to deflection from their fixed positions around the atom shows itself in the form of a strain, and is comparable to the tension observed in the case of a bent metal spring."

The following are a few excerpts from the work of Lewis [17] which apply to unsaturated or endothermic compounds: "Unsaturation connotes a set of properties, all of which indicate a looseness of structure and lack of stability." "The properties of unsaturated organic substances have proved to be in very good accord with the 'strain theory' proposed by Baeyer (1895) according to this theory, a bond tends to lie in a straight line joining atom to atom, and the directions of the four bonds emanating from a single carbon atom are those determined by tetrahedral symmetry. Whenever the bonds are forced out of these positions there is supposed to be a state of strain which manifests itself through instability and the general characteristics of unsaturation." "Thus the various phenomena which indicate the breaking of a bond . . . such phenomena as the disruption of the molecule or the

* "The explosive process is, however, not conditioned on, an exothermic reaction, it is unimportant in this connection whether a compound is endothermic or exothermic, and in no case can a negative heat of formation be considered an index of an explosive potentiality." "Explosives," Brunswig; Munroe & Kibler, John Wiley & Sons, N. Y., page 8.

[15] *Ber.*, **18**, 2278 (1885).

[16] "Theories of Organic Chemistry," Henrich, 1922, page 19–20, John Wiley & Sons, N. Y.

[17] "Valence and the Structure of Atoms and Molecules," Lewis, 1923, page 88–90, Reinhold Publishing Co., N. Y.

rearrangement of radicals * . . . almost invariably occur in the neighborhood of such a seat of unsaturation. If not as an accurate scientific analogy, at least as a metaphor, we may liken the phenomena to the result of a strain applied to some portion of a mechanical system of elastic bodies."

This inherent internal strain accounts for the energy released by the endothermic compounds when they break down, and shows itself as heat when such materials burn. For instance, when a compound like ethane burns to carbon dioxide and water, the value in calories developed by the combustion is less than the value developed by the combustion of the elements which make up the methane molecule. But when acetylene is burned, the heat produced by the combustion far exceeds that produced by combustion of an equivalent quantity of the constituent elements. The difference is to be found, in the first instance, in the energy required to break the valence bonds; and in the second instance, the energy given off when the internal strain is released. In the words of Henrich:[18] "In interpreting these facts it is necessary to assume *not* that energy is required to break the double bond between the carbon atoms, but that *energy is actually set free* during this process. . . . This difference has been explained by supposing that a certain degree of tension is developed within the molecule by the union of the second pair of valencies of carbon to form a double bond, and that such an atomic arrangement must, therefore, be regarded as representing a definite amount of stored-up (i.e. potential) chemical energy. If the equilibrium is a system of this kind is *disturbed in any way* this energy is set free. Thus in the process of burning it appears as heat and serves to increase the total heat of combustion of the substance."

The condition of equilibrium of the endothermic compound has been compared to a boulder lodged on the slope of a mountain. It requires a certain amount of energy to dislodge

* Writer's Note: Mercury fulminate (which is an unsaturated compound) when exposed to high temperatures is converted into pyrofulmin which retains the original crystalline form of the fulminate. This action is probably due to a migration of the radicals which leads to their escape from the crystal without destroying the main structural part of the crystal lattice.

[18] "Theories of Organic Chemistry," Henrich, 1922, John Wiley & Co., N. Y., page 328. Italics are the writer's.

it, but when dislodged it releases a far greater amount of energy than was applied. Lewis and Randall [19] say, "So in thermodynamics a system may be in a state of rest and if slightly disturbed, may revert to this same state of rest, but if largely disturbed it may proceed toward some entirely new condition of equilibrium." The energy required to release the crystal from its original form may vary with different compounds, from a rather large magnitude to zero as a limit, and so with the endothermic compound, its stability may approach zero as a limit. Nitrogen iodide is an example which very closely approaches the limit. It may be kept under water, but explodes spontaneously when dry. This is probably an instance of the effectiveness of protection of the surface, by satisfaction of the *unsaturated surface* valencies.

This endothermic condition is found in most initiators of detonation, and is probably a most important prime condition for such agents. It will be noted that under sound it was stated that the strain in a crystal disappears with the velocity of sound when the crystal is released from stress. In the endothermic compound we have a strain inherently within the crystal. Any sudden disturbance of the crystal or part of the crystal, such as breaking, may allow the strain to disappear with the velocity of sound, and thereby communicate the disturbance to surrounding crystals.

In the introduction an attempt was made to show how inadequate was the present knowledge of explosives, in the liquid and solid condition, Travis [20] sums up this condition, for the solid state, in general, as follows: "We really know very little about matter in the solid state. . . . We know very little about the effect of various forms of energy, such as light, heat, electricity, when passed through solids, and even that which we do know is superficial. In other words our ignorance of the real nature of solids is almost perfect." Travis should have included among the forms of energy, the effects of which are unknown, that of mechanical vibrations of great intensity. Another quotation from Travis which

[19] "Thermodynamics," Lewis and Randall, 1923, McGraw-Hill Book Co., N. Y., page 19.

[20] "Mechano-Chemistry and the Colloid Mill," Travis, 1928, Reinhold Publishing Co., N. Y., page 15.

leads up to the desirable method of treatment of our subject, is given as follows: ". . . for the numerical properties may be called the fundamental ones and it is investigation of these constant properties which really advances the science."

There are a number of numerical values, of an explosive decomposition or detonation, which might give a solution or aid in the solution of the phenomenon. These are the volume of gas produced, temperature attained, the pressure-time curve, the rate of reaction, the rate of detonation, and the density of the explosive. The volume of gas produced can be determined under standard conditions, *after*, the explosion, but not at the instant of explosion. The temperature attained is not known, therefore, the volume of gas at the time of explosion is not known, and likewise the pressure, which is dependent on both temperature and volume of gas, is not known. The rate of reaction is not known. On this subject Lewis and Randall [21] say: "What reactions are possible and their yields can be known by thermodynamics, but the time element is unknown" and "The rate of reaction is determined by factors which have hitherto eluded any exact analysis." And again, "When the rate of a chemical reaction is involved, the time required to establish an equilibrium depends upon factors which we may suspect to be often fundamentally analogous to viscosity, but which are still very obscure."

There remains for detonating explosives only the rate of detonation and density which are determinable as fundamental numerical characteristics. Very few of the fundamental values of the *pure* explosive compounds have been determined but for a few of these compounds these two characteristics have been very closely approximated. The granular explosives may be detonated in any condition from a loose powder to a mass compressed into a dense state almost equaling the actual specific gravity of the individual crystals. The rate of detonation has been determined for several explosives at densities over this entire range. We then have two numerical values and can determine the relation between them if any exists.

[21] "Thermodynamics," Lewis and Randall, 1st Ed., 1923, McGraw-Hill Book Co., N. Y., pages 3, 4, 17.

It is now desired to show the little that is known and to correlate that little, to show how it falls in with the present knowledge of the molecule and the crystal. The first step in that direction will be to describe the method of determining the rate of detonation, which is the most significant numerical property of explosives known at present. The rate of detonation may be determined by the use of Mettagang's Recorder.

All of the rates of detonation given in this paper were determined by the use of the Mettegang's Recorder. Described in its simplest form, it consists of, (1) A recording drum which may be driven at high speeds; (2) Induction coils with primary and secondary circuits; (3) A measuring microscope; (4) Spark points attached to the secondary circuits of the induction coils and held in position close to the periphery of the recording drum, completing, through a small air gap, the secondary circuits. The procedure for making a determination is accomplished by first passing the wire carrying a primary circuit, through each of two points in the explosive column at a known distance apart. When the recording drum is revolving at the proper speed the charge is fired. The breaking of the two primary circuits, successively, as the wave passes, generates a high potential in the two corresponding secondary circuits, causing two sparks to jump to the surface of the revolving drum. Knowing the peripheral speed of the surface of the drum, the distance between the wires of the primary circuits at the points where passed through the explosive, the distance between the sparks produced on the drum, may be measured and the time of detonation calculated, and from the time the rate of detonation in meters per second. An accurate determination depends, largely, upon the uniform breaking of the wires carrying the primary circuits, which pass through the explosive column.

Kast [22] acknowledges meeting difficulties in determining the rate of detonation by this method, with explosives confined in metallic tubes, and is unable to assign the cause, definitely. He says, a main requirement is, that the measuring wires be fastened so that they are not displacable. He found it necessary to use a higher current value with metallic tubes, and

[22] "Zeit. f. d. Gesamte S. u. S.," 1913, page 65.

mentions electrical disturbances caused by the metallic mass in the circuit. Kast, however, succeeded in securing reliable results by using 2 to 3 mm. holes in the tubes, in which were inserted vulcan fiber plugs, and through which the wires were passed and securely held.

The explosives used in the tests, reported in this paper, except those specifically described, were loaded, directly, into Shelby seamless steel tubing, reamed to an inside diameter of one inch. The wall thickness was approximately three-sixteenth of an inch. About four inches at each end of the steel tubes contained no explosive. Detonation was initiated by means of fulminate detonators and tetryl boosters. The writer, also, encountered difficulties in using this scheme, when the holes in the tubes were 0.120 inches in diameter, even when double cotton covered magnet wire was used. It was found that the rates secured with this set-up were generally, much higher than the actual rates. It was decided that the cause of this great error might be that the primary circuits were coming into contact with the steel tubes during the passage of the wave. In such a situation the circuits would not be broken until the tube was destroyed at the points where the wires were shorted and, therefore, there would be a lag in the breaking of all circuits. If the lag in the breaking of all of the circuits were equal no error would result. However, it is reasonable to expect a greater lag in the breaking of the first circuits, because, at the beginning of the steel tube, a greater force is required to start the disruption of the tube, than is required to continue it, once started. A study of the results seemed to confirm this assumption. A few results were approximately correct, indicating determinations in which the circuits were not shorted, others were approximately 50 per cent. higher than the actual, indicating that all circuits were shorted, and still others were as much as 100 per cent. higher than the actual, indicating, probably, that the first circuits, only, were shorted. Practically none of the results indicated rates less than the actual.

The difficulty was, however, overcome when the holes in the tubes were increased to 0.25 inches in diameter. A bare copper wire was used, supported centrally in the hole, by being passed through friction tape, which had been wrapped

around the tubes. This result seems to indicate that insulation, of itself, is not sufficient to prevent contact of the wires with the tubes, but that a certain minimum space is necessary to accomplish that purpose. This indicates that there is *a movement of the explosive material*, which causes ordinary insulation to be ineffective, but that insulation may be accomplished by leaving a sufficient space, to allow the movement of the material without bringing the wires into contact with the tubes. This reasoning was one of the first steps toward the development of the physical theory of detonation, and is the most significant detail of the determination.

The accuracy and reliability of this method can best be shown by the results of determinations of the rate of detonation of tri-nitro-toluene (T.N.T.). This material, in the cast condition (solidified from the liquid), has been chosen for this illustration, because of its reproducibility. A sample of an explosive in the granular form must be described in minute detail to make it possible for another person to produce a comparable sample. For example, the pressing operation required to secure a high density, may cause stresses in the crystals the effects of which are unknown. Joffe says:[23] "An optical investigation of natural crystals has shown that they already have permanent stresses, ... A prolonged annealing at 600 to 700° C. is necessary in order to remove the stresses and make the crystals really uniform." And again: "In fact . . . , the size and shape of a solid body is no longer a single valued function of the external forces as our reasoning would require, but depends on the *whole preceding history*. Each stress exerts an influence that dies away very slowly. In a given state we meet traces of stresses which ceased a long time back, but remnants of which are still active at the present." It would seem then, that a material cooled from the liquid state to a solid, without any other treatment, would be more reproducible than a granular material pressed to a definite density.

Kast[24] determined the rate of detonation of cast T.N.T. (density 1.59) in iron tubes using a booster of picric acid with various diameters of charge with results as follows:

[23] "The Physics of Crystals," 1st Ed., 1928, McGraw-Hill Book Co., N. Y., pages 24 and 47.

[24] "Zeit. f. d. Gesamte S. u. S.," 1913, pages 65, 88, 133, 155, 172.

Dia. of Charge Mm.	Rate of Detonation M./Sec.	
21	6700	6555
29	6700	
75	6595	
160	6690	
222	6675	
300	6710	
average	6678	

The writer has determined the rate of cast T.N.T. at a density of 1.58 in steel tubes with inside diameter of one inch, using a tetryl booster. These trials gave results indicating rates of 6700, 6627, 6595, with the average of 6640 m./sec. These figures indicate that there is no determinable difference in rates with different diameters of charge and different boosters and that given an explosive in a reproducible state the results secured by different operators and equipment can be reproduced.

There are three sources of error which enter into the results, as determined with Mettagang's recorder, the magnitude of which can be accurately determined. These are the error of reading the points on the drum,the instrumental error and the error of measurement of the distance between the primary circuits through the explosive column. Experiments were carried out by four operators at the Bureau of Mines to determine the value of each of these errors. The first two were found to be equal to 0.02 mm. in the reading. The third was found to be equal to 1.0 mm. Table 1 shows

TABLE 1.

Magnitude of Errors.

Error of Reading Mm.	Rate of Expl. M./Sec.	Max. Error with Drum Speed.		Error Due to Measurement of Tube M./Sec.	Possible Difference of Two Rates on Same Tube with Drum Speed.	
		90 R.P.S., M./Sec.	120 R.P.S., M./Sec.		90 R.P.S., M./Sec.	120 R.P.S., M./Sec.
04	7500	48	36	8	112	88
04	7000	40	32	7	94	78
04	6500	36	28	6	84	68
04	6000	32	24	6	76	60
04	5500	28	20	6	68	52
04	5000	24	16	5	58	42
04	4500	20	16	4	48	40

the value in meters per second which these errors would cause for explosives having various rates of detonation. Two values were secured, on a practically identical column of explosive, by the use of four primary circuits; Nos. 1 and 2 at the detonator end of the column, and Nos. 3 and 4 at the opposite end each one meter from Nos. 1 and 2, respectively. The distance between No. 1 and No. 2 was one inch in every case. It was found that the two results, secured on the same column fell within the value of the known errors in 74 per cent. of the trials. It is indicated, therefore, that the unknown errors must be comparatively small.

The rates of detonation of mercury fulminate, determined by the writer,[25] are given in Table 2 and are presented in Fig. 1 plotted against apparent density. The results fall so

TABLE 2.

Explosive.	Density.	Confinement.	Rate.	Average.
Mercury fulminate.....	2.99	0.007 in. copper	3971	
Mercury fulminate.....	2.15	0.007 in. copper	3304	
Mercury fulminate.....	1.82	0.007 in. copper	3122	
90–10 Ful-chlorate.....	2.66	0.006 in. copper	3738	
90–10 Ful-chlorate.....	1.98	0.006 in. copper	3116	
90–10 Ful-chlorate.....	1.65	0.006 in. copper	2844	
80–20 Ful-chlorate.....	2.64	0.007 in. copper	3896	3913
80–20 Ful-chlorate.....	2.64	0.007 in. copper	3930	
80–20 Ful-chlorate.....	1.99	0.007 in. copper	3223	
80–20 Ful-chlorate.....	1.81	0.007 in. copper	3040	
80–20 Ful-chlorate.....	2.62	0.010 in. copper	3951	
80–20 Ful-chlorate.....	1.91	0.010 in. copper	3099	
80–20 Ful-chlorate.....	1.71	0.010 in. copper	2886	

Diameter of explosive column 0.220 inches in all trials.

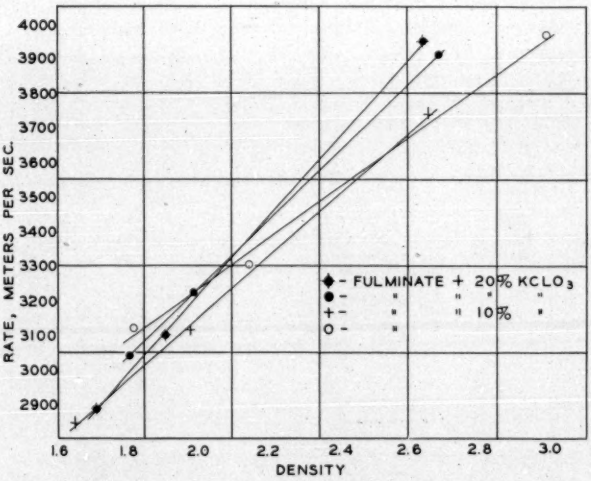
well into the pattern of a straight line curve that it is not conceivable to consider them in any other way.

As it is the intention to make use of the relation between density and rate of detonation, in the development of the theory, it is desirable to discuss, at this point certain conditions which are active to cause some of the rates, not to conform to the straight line curve. These influences can be shown to be properties which are not inherent in the explosives, but are caused by impurities and methods of pro-

[25] "Army Ordnance," Vol. 6, No. 34, 1926, pages 302–304.

cedure, which could be removed and corrected, with a consequent improvement in the conformity to the straight line curve. It is for this reason that Fig. 2. and 3 are presented at this point. It will be noted, in Fig. 2 that the Grade II, T.N.T., is more erratic than the Grade I, and that the curve is steeper for the Grade II. In Fig. 3 the same tendency is noticeable, that is, the tetryl with 2 per cent. of stearic acid

FIG. 1.



does not conform so well to the straight line and the curve is steeper than for the same material without stearic acid. This tendency of impure and insensitive explosives to increase in rate rapidly with increase of density and then, with further increase of density to tend to fall below the straight line, has confused some observers into the idea that such a curve represents the facts better than a straight line. This error has been promoted by the consideration of data secured by the use of impure compounds, insensitive materials and mix-

FIG. 2.

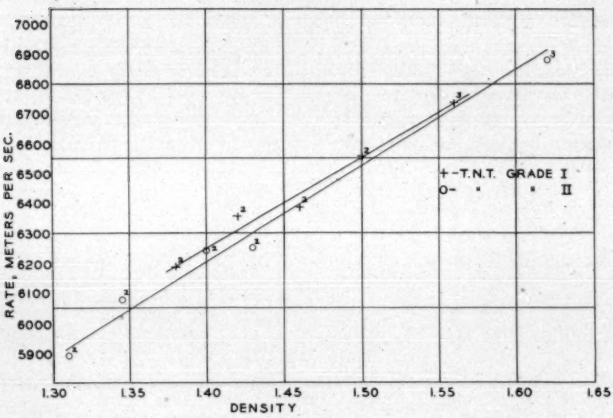
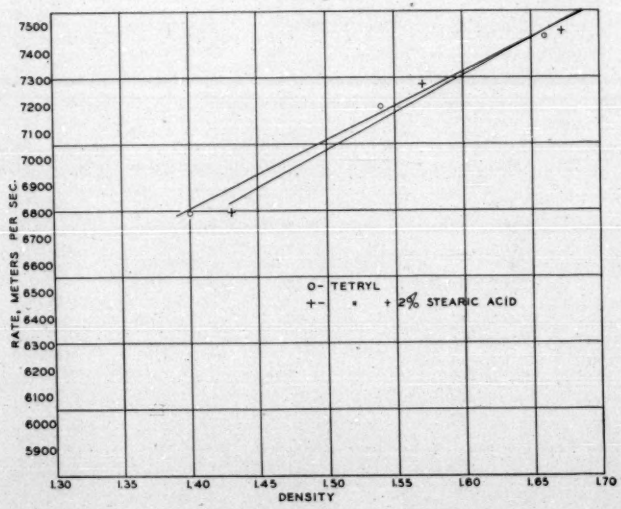

RATE, METERS PER SEC.
7000
6900
6800
6700
6600
6500
6400
6300
6200
6100
6000
5900
1.30
1.35
1.40
1.45
1.50
1.55
1.60
1.65
DENSITY
+-T.N.T. GRADE I
O- " " II

FIG. 3.


RATE, METERS PER SEC.
7500
7400
7300
7200
7100
7000
6900
6800
6700
6600
6500
6400
6300
6200
6100
6000
5900
1.30
1.35
1.40
1.45
1.50
1.55
1.60
1.65
1.70
DENSITY
O- TETRYL
+- " + 2% STEARIC ACID

tures such as the dynamites. Unfortunately very few of the explosive compounds have been produced in a chemically pure condition. Therefore, a real test of the adherence to the straight line has not been made.

Now if we, again, refer to Fig. 1 we may note that not only is there no tendency of the rate to fall off, but there even seems to be a tendency to fall above the curve at high densities. A condition existed in the samples of fulminate used in these tests which did not exist in the material used in any of the other tests given in this paper. The fulminate had been pressed in detonator cups and was removed to make the charges of lower density. This fact caused the granulation of the material to be more nearly comparable in the tests at different densities than was the case in the tests of other explosives. In all the other tests the explosives were pressed into the tubes from fresh material and, therefore, the higher the density, the higher the pressure required to attain it and consequently the finer the granulation of the material after pressing. It is known that large crystals of endothermic compounds * cause the materials to be more sensitive and large crystals of exothermic compounds cause the materials to be less sensitive. The later effect is shown by Taylor and Leitch in tests of T.N.T. in the sand test bomb.[26] The effect of a change of granulation on the rate of detonation will become more apparent when it is discussed later in this paper.

Another reason for the greater uniformity of the results given in Fig. 1 is the fact that all of the material had been subjected to the same maximum pressure, thus eliminating the unknown effect of such treatment.* The fact that fulminate is a very sensitive explosive, also causes the results to

* "Furthermore it has been recognized and noted that the sensitivity is dependent upon the crystal size; this sensitivity being so great as to render the handling of the material extremely dangerous if the crystals exceeded certain sizes." U. S. Patent No. 1,914,530, Lead Azide, June 20, 1933, Wm. H. Rinkenbach.

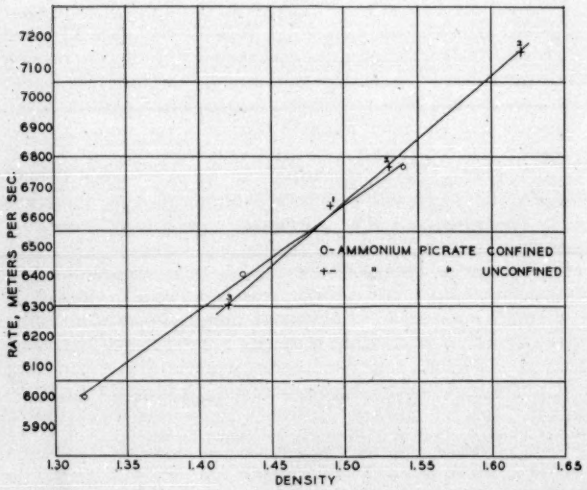
[26] Reports of Invest. No. 2526, Dept. of the Interior, Bur. of Mines.

* "Even with a deformation which is macroscopically as homogeneous as possible, such as the compression of a single crystal disk between plane surfaces, disturbances of the lattice appear which lead to an increase of the shear resistance." "Elasticity, Plasticity and Structure of Matter." Houwink, 1937, Cambridge Press, London, page 115.

conform more truly to the straight line curve. In other words fulminate has the explosive quality in a high degree. In investigations to ascertain the nature of a natural law a material should be selected, having the quality in a high degree. For example one would naturally select a true gas to illustrate the nature of the gas laws. Otherwise accidental and border line phenomena would interefere and mask the pertinent facts.

Still another condition effecting the rate of detonation is shown in Fig. 4. This shows the rate of ammonium picrate

FIG. 4.



confined in steel tubes, compared to the same explosive, in the unconfined condition. It will be noted, that in the unconfined condition, the curve is steeper, and that the data conform more strictly to the straight line curve, than is the case with the same explosive in the confined condition. It is indicated, that the method best suited, to determine the true numerical

characteristic of the explosive, is the one which is most free from the influence of the environment. Contrary to the common opinion, it is also indicated, that the rate is not increased, but is actually decreased, at the higher densities, by confinement. The steel tube has interfered with the propagation of the wave by tending to prevent the distortion of the explosive. Such interference becomes more effective as the density is increased. Any agency which tends to prevent the distortion of the molecules will tend to damp out the detonation wave.

Summing up, there are five major factors which tend to cause the rates of detonation to seem not to be perfectly represented by a straight line curve. These influences are: 1st., the impurity of the compounds, 2nd., the difference in granulation at the different densities, 3rd., the interference of confinement, 4th., the effect of high pressures on the physical properties of the crystals and 5th., the effect of use of insensitive explosives.

It can be seen, then, that the rate of detonation tends to produce a straight line, when plotted against density, and that under more nearly ideal conditions, the conformity to such a curve would be extremely close. It is, therefore, proposed to represent all of the curves as straight lines, although the rates of three of the explosives, viz. tetryl, picric acid and ammonium picrate show a tendency to round over at the highest densities.

A study of the curves shows that for each explosive the curve has a different equation. No significance, however, has ever been ascribed to this fact. Nevertheless, it is a most important characteristic of the explosives, and illustrates the point stressed in the introduction, i.e. that explosives must not be classified by formulæ which use the rate of detonation as one of the factors, because the rate of detonation varies with density, and by a different factor for each explosive.

(To be continued)

New Art Medium.—Ten tons of stainless steel—the first piece of heroic sculpture ever cast in this new art medium—arrived in New York recently and was assembled for installation over the main entrance of the Associated Press Building in Rockefeller Center. Designed by Isamu Noguchi, 35-year-old Japanese-American artist, and winner of the National Competition for the Associated Press Building plaque, the huge panel is the largest metal bas relief ever cast. Designed as a symbol of "News" the panel depicts in bold and simple lines the heads and torsos of five men. Four of them are working with the swift tools of modern journalism—the teletype, wirephoto, camera, and telephone, while the fifth one carries the pad and pencil—trademark of all reporters. For eight months, Noguchi and workers in the Boston foundry of the General Alloys Company have been struggling with the experimental problem of casting the huge panel which measures approximately 17 × 22 feet. The full-scale plaster model was first divided into nine sections. One of the chief technical problems of casting each of these sections was that the stainless steel must be poured at such terrific heat that it would destroy any ordinary sand mold. H. H. Harris, president of General Alloys, explained recently, "We solved this problem by rigging up a couple of 'bath tub' reservoirs on top of our mold, and then building a whole network of runners that would carry the metal quickly and evenly over the whole surface. The 'bath tubs' were fitted with big plugs that could be pulled out simultaneously, and in one explosive second the casting is completed. The action is so fast that there is not time for the sand to be disturbed by the white-hot metal." The huge sections were then polished and finished. Using precision power tools, the edges were trimmed to the exactness of 1/1000 of an inch. The giant panel was then welded into three sections. Noguchi worked side by side with the men in the foundry during the entire period, and said that the operation was "like working on a tremendously tough and delicate watch spring—every time you touched one small part of it the whole thing would shift." The three sections of the panel arrived by truck in New York from the Boston foundry of the General Alloys Company and were hoisted by cranes into the space already built for it above the entrance of the Associated Press Building. Like a giant puzzle, the three sections were bolted to a thirty-three inch steel "I" beam above the doorway and slipped into place one on top of the other.

R. H. O.

A THEORETICAL DETERMINATION OF BREAKDOWN VOLTAGE FOR SPHERE-GAPS.

BY

J. M. MEEK,

Department of Physics, University of California, Berkeley, California.

ABSTRACT.

The potentials required for breakdown between spheres are calculated on the basis of the streamer theory of spark discharge. This theory is founded on atom-physical considerations, so that the calculations are not of the usual empirical nature. Agreement within about 3 per cent. of the values determined experimentally is obtained in the case of the symmetrical sphere-gap for spacings up to a sphere diameter. The effect of variation of air density is also considered and the calculations are again found to be in close agreement with experiment. The Toepler discontinuity is explained in terms of the new theory, which predicts a transition region between two types of mechanism in the range of spacings where the discontinuity is observed, and which further accounts for the known increase in scattering of the measured potentials in that region.

INTRODUCTION.

The calibration of the sphere spark-gap for voltage measurements is of considerable importance to engineers and has been the subject of much investigation during recent years. A survey of the literature now indicates that there is reasonable agreement between the experimental results of the various authorities.[1] However, the lack of an adequate theory of spark discharge has precluded the theoretical calculation of the voltage required to cause breakdown, though a number of empirical formulæ, notably that given by Peek,[2] have been developed to enable calculations of breakdown voltage to be made. In general these formulæ represent the relation between breakdown voltage and gap length over a certain range

[1] J. R. Meador, *Trans. A. I. E. E.*, **53**, 942 (1934). "Revised Sphere-gap Sparkover Voltages," *Trans. A. I. E. E.*, **55**, 783 (1936). W. Dattan, *Elektrotechnische Zeitschrift*, **57**, 377 (1936). E. Hueter, *Elektrotechnische Zeitschrift*, **57**, 621 (1936). F. S. Edwards and J. F. Smee, *Journal I. E. E.*, **82**, 655 (1938). R. Davis and G. W. Bowdler, *Journal I. E. E.*, **82**, 645 (1938).

[2] F. W. Peek, "Dielectric Phenomena in High Voltage Engineering" (McGraw-Hill, 1929), page 73.

of values but fail when extrapolated outside that range. The tendency is to base such formulæ on the supposition that breakdown takes place when the gradient at the sphere surface attains a particular value which is dependent on the radius of the sphere, and thus one frequently sees the statement that the breakdown strength of air is a function of electrode curvature.

The evolution of a new theory of spark discharge now enables the calculation of the breakdown strength of air for various electrode configurations to be made on an atom-physical basis without recourse to empiricism. Further the theory is found to explain many observed sparking phenomena. It is thus thought profitable to present a brief outline of the theory together with the results obtained when it is applied to the calculation of the breakdown potential of the sphere gap.

SPARK DISCHARGE THEORY.

The new theory of spark discharge has been discussed extensively elsewhere [3] and only the important features relevant to the present article will be given here. The theory considers the breakdown of a uniform discharge-gap between parallel plate electrodes to occur by the transition of an electron avalanche, proceeding from cathode to anode, into a self-propagating positive streamer which develops from anode to cathode to form a conducting filament bridging the electrodes. The criterion put forward for such a transition is that a streamer develops when the radial field about the positive space-charge in an electron avalanche attains a value of the order of the external applied field. For then photo-electrons in the immediate vicinity of the avalanche will be drawn into the stem of the latter and will give rise to a conducting filament of plasma which proceeds in the direction of the cathode as a self-propagating positive streamer. The theory thus depends on ionization by electrons and photo-ionization in the gas, and dispenses with the classical assumption of ionization by positive ions in the gas or secondary actions at the cathode.

[3] J. M. Meek, *Phys. Rev.*, **57**, 722 (1940). L. B. Loeb and J. M. Meek, *J. App. Phys.*, June and July issues (1940).

The application of the above criterion leads to an equation for the breakdown of a uniform gap

$$\alpha d + \log_e \frac{\alpha}{p} = 14.46 + \log_e \frac{X}{p} + \frac{1}{2} \log \frac{d}{p}, \qquad (1)$$

where d cm. is the gap length, p mm. Hg is the gas pressure, X volts per cm. is the applied field strength and α is the Townsend primary coefficient of ionization by electrons. Reference to curves which relate α/p with X/p enables the breakdown potential of a given gap at a given gas pressure to be calculated. Satisfactory agreement between calculation and experiment is found in air for values of pd down to about 200 mm. Hg × cm., while classical theory can be shown to apply at lower values of pd. For a gap of 1 cm. in air at atmospheric pressure the calculated breakdown potential is 32,200 volts as compared with the measured value of 31,600 volts.

When the gap is not uniform αd has to be replaced by the integral of α across the gap, so that the breakdown equation becomes

$$\int_0^d \alpha dx + \log_e \frac{\alpha_A}{p} = 14.46 + \log_e \frac{X_A}{p} + \frac{1}{2} \log \frac{d}{p}, \qquad (2)$$

where α_A and X_A are the respective values of α and X at the surface of the anode. This equation must again be adjusted for gaps in which the lack of uniformity of the electric field is such that α is virtually zero over most of the mid-gap region, and only becomes significant near the electrode surfaces. Streamer formation at the anode will now be initiated by electron avalanches which have their origin in the gap in the region of the anode, and electron avalanches will not traverse the full gap from cathode to anode. Such conditions obtain in the case of the corona discharge, and will also be shown to occur for breakdown between spheres when the gap length is sufficient. In such a case the equation for breakdown becomes

$$\int_R^{R+a} \alpha dx + \log_e \frac{\alpha_A}{p} = 14.46 + \log_e \frac{X_A}{p} + \frac{1}{2} \log_e \frac{a}{p}, \qquad (3)$$

where R cm. is the radius of the sphere and a cm. is the distance of the point of origin of the electron avalanche from the

sphere surface. For the purpose of calculation this point may be taken as that where the value of α is unity.

THE CALCULATION OF BREAKDOWN POTENTIAL.

The potential gradient between two spheres along the line of centers is such that the gradient is always higher at the surface of each sphere than that at mid-gap. The variation of gradient decreases with decreasing gap-length, and for short enough gaps the gradient is virtually uniform. However the variation of the ionization coefficient α across the gap will be much more pronounced, for in the region of $X/p \sim 40$ the value of α/p varies approximately exponentially with X/p.

Curves giving the variation of X and α across a 2.5 cm. gap between spheres of 12.5 cm. radius for a potential difference of 70,000 volts are shown in Fig. 1. The voltage gradient X is determined from the expression given by Peek [4] for the gradient at any point on the line of centers, viz.

$$X = \frac{2d[d^2(f+1) + 4y^2(f-1)]V}{[d^2(f+1) - 4y^2(f-1)]^2},$$

where

$$f = \frac{d/R + 1 + \sqrt{(d/R+1)^2 + 8}}{4},$$

d cm. is the gap-length, y cm. is the distance of the point under consideration from the mid-point of the line joining the centers of the spheres, R cm. is the sphere radius, and V is the voltage between the spheres. The values of α used to obtain the curve in Fig. 1, and as used throughout this article, are those given by Sanders [5] for air.

The value of $V = 70{,}000$ volts chosen in Fig. 1 is that which leads to such values of X and α in the gap that equation (2) is satisfied, i.e. 70,000 volts is the calculated breakdown potential for the particular gap under consideration.* This

[4] See ref. 2, page 68.

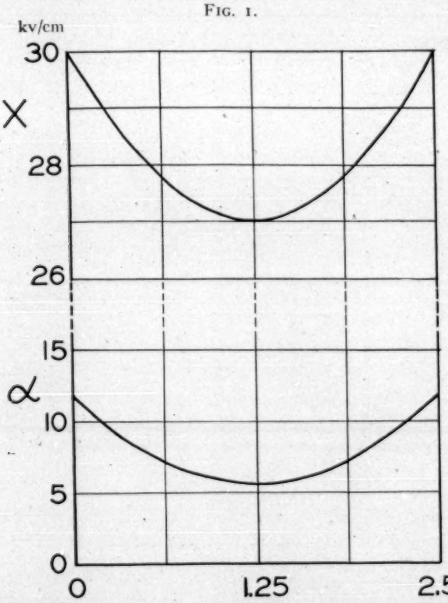
[5] F. H. Sanders, *Phys. Rev.*, **41**, 667 (1932).

* The voltage which gives the solution of equation (2) is obtained by a process of trial and error. For some particular voltage the values of X and α are determined at a sufficient number of points in the gap to enable the calculation of $\int_0^d \alpha\, dx$ by Simpson's rule. Then the values of X_A, α_A and $\int_0^d \alpha\, dx$ are inserted in the equation and the difference between the left-hand and right-hand sides of

is in close agreement with the measured value of about 72,000 volts.[1]

As in the case of the uniform gap, for breakdown at the minimum voltage, an electron avalanche will be originated by

FIG. 1.



Curves to show the variation of field strength X and the primary ionization coefficient α across a 2.5 cm. gap between spheres of 12.5 cm. radius when the applied potential difference is 70,000 volts.

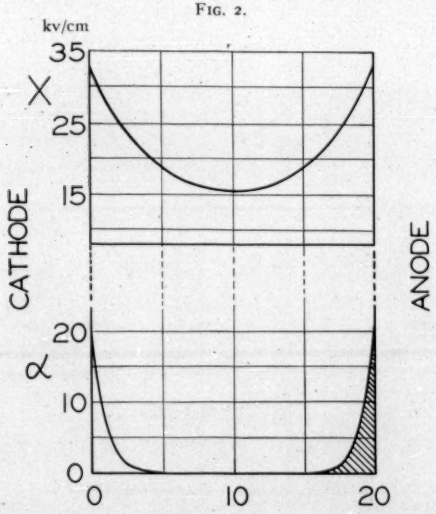
an electron leaving the cathode and will travel across the gap to the anode. There the ion density in the avalanche is such that it gives rise to a positive streamer which develops from

the equation is evaluated. The process is repeated for several voltages and a curve is plotted to relate voltage with the difference between the two sides of the equation. The voltage at which this difference is zero is that which gives the solution of the equation, and is the breakdown voltage. The solution of equation (3) is performed in a similar manner.

anode to cathode to form a conducting filament bridging the gap, and so causes breakdown.

When the gap length is large however the voltage gradient for breakdown between the spheres is such that the value of α is virtually zero over most of the mid-gap region. This is illustrated in Fig. 2, which shows the variation of X and α across the gap for a 20 cm. gap between spheres of 12.5 cm.

FIG. 2.



Curves to show the variation of field strength X and the primary ionization coefficient α across a 20.0 cm. gap between spheres of 12.5 cm. radius when the applied potential difference is 407,000 volts.

radius at the calculated voltage required for sparking. In this case the breakdown is again due to the development of a streamer from the positive sphere, but now the avalanche which initiates the streamer will not have its origin at the cathode. Such avalanches starting from the cathode will diffuse considerably in the region of low α in mid-gap and will not reach the anode in a filamentary form. A positive streamer at the anode will now be originated by an avalanche

which forms in the mid-gap region near to the anode. This avalanche will give rise to a value of $\int \alpha dx$ as shown by the shaded area of Fig. 2. The process is thus more akin to the corona discharge formed at a conductor in free space.[5] The voltage required to cause the formation of a positive streamer is then that which leads to the solution of equation (3) where the value of $\int_R^{R+a} \alpha dx$ is that indicated by the shaded area of Fig. 2, and is thus $\frac{1}{2}\int_0^d \alpha dx$ where d is the gap length.

In the case under consideration, for a 20 cm. gap between 12.5 cm. radius spheres, the formation of a positive streamer will immediately cause breakdown of the gap, for the voltage is very much higher than that required to cause breakdown of such a gap between a positive point and a negative sphere. However if the gap length is sufficiently increased a gap length will be reached at which the voltage is insufficient to cause such breakdown, i.e. streamers will form but will be unable to cross the gap. This accounts for the experimentally observed fact [6] that corona is observed to precede breakdown when the gap length is larger than about $8R$ where R is the sphere radius. For such long gap lengths the breakdown voltage curve is found to follow that for the positive point to negative sphere. The present article is however concerned with gap lengths only up to $2R$, where corona is not observed to precede breakdown for the above reasons. Further, up to such a gap length of $2R$, reasonably symmetrical conditions can be obtained and the influence of sphere supports and external objects on the field between the spheres will be slight.

The various manners in which the breakdown of a sphere-gap takes place are then dependent on the spacing between the spheres, and can be grouped as follows:

I. The electron avalanche proceeds all the way across the gap from the cathode to anode and there forms a positive streamer which leads to breakdown. The circumstances leading to breakdown are then similar to those for the uniform gap and only occur for spacings in which the variation of field is slight, as illustrated in Fig. 1. The breakdown voltage is determined by equation (2).

II. The electron avalanche which initiates a positive streamer at the anode, and so causes breakdown, has its

[6] See ref. 2, page 68.

origin in the gap near the anode. Such a case is illustrated in Fig. 2, and occurs when the voltage gradient varies so much across the gap that the value of α is virtually zero over most of the mid-gap region. The breakdown voltage is determined by equation (3).

III. Similar to II except that the voltage required to produce a positive streamer is less than that required to propagate it across the gap. Such a condition obtains for gap lengths greater than about $8R$, when corona is observed to appear and the voltage has to be further raised to cause breakdown.

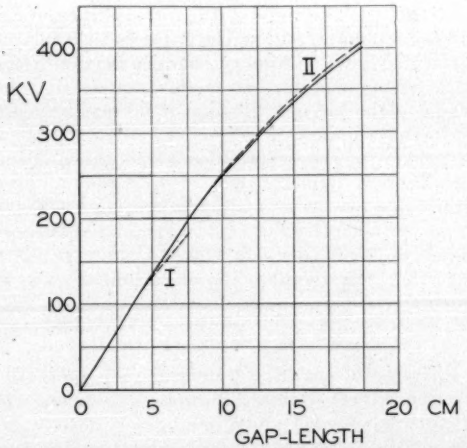
Between the regions I and II there is a transition region which is of much interest and will be discussed later. The region III is not considered in the present article as it occurs for gap lengths much in excess of those used for calibration purposes and is of course much influenced by the effect of external objects on the sphere gap field.

Curves to show the calculated and measured breakdown potentials for breakdown between 12.5 cm. radius spheres are given in Fig. 3. The experimental curve is that given by Hueter [1] for a symmetrical sphere gap, i.e. with voltages $+\frac{V}{2}$ and $-\frac{V}{2}$ on the two spheres. In region I, for the shorter gap lengths, the calculated voltages are in close agreement with experiment up to a gap length of about 4 cm., when they start to fall below the measured values. At a gap length of 7.5 cm. such calculations give a voltage of 183,000 volts as compared with the measured 200,000 volts. However the value of α is very low in the mid-gap region, and is less than 1 for the central 3 cm. of the gap. One would then expect that breakdown here occurs on the basis of region II, and actually calculations on this basis give 197,000 volts as that required for breakdown. For yet longer gaps, where the value of α is still further decreased in the mid-gap region, the breakdown mechanism goes over definitely into the region II, and the calculated curve is seen to agree closely with that measured.

The theoretically predicted transition region between I and II is confirmed by observation. Hueter [1] found the scattering of his voltage measurements to increase to a peak

at about 8.0 cm. spacing. Further, Dattan,[1] again in measurements of the breakdown voltage between spheres of 12.5 cm. radius, observed a considerable scattering of his measurements in that region. The peak value of the scattering was as much as 6 per cent., and was greater than 2 per cent. for spacings between 5.25 and 7.75 cm. Reference to Fig. 3 shows that this is just the region in which such scattering is to be expected on the basis of the present theory. For the

FIG. 3.



The calculated and observed curves for the breakdown potential between spheres of 12.5 cm. radius. The full curve is that observed experimentally. The dashed curves are those calculated.

value of α becomes so low in the mid-gap region that the chance of a breakdown occurring by mechanism I is extremely remote. Many electrons will have to leave the cathode before a particular electron avalanche crosses the gap under such a propitious chain of circumstances that it succeeds in giving rise to a streamer at the anode.[3, 7] However if the voltage is raised slightly above that calculated by mechanism I, not

[7] L. B. Loeb, "Fundamental Processes of Electrical Discharge in Gases" (John Wiley, 1939), page 424.

only is there an increased chance of a breakdown due to an electron avalanche which leaves the cathode but also breakdown can occur as a result of avalanches originated by electrons in the gap itself. Thus the chance of breakdown is materially increased, and while an occasional breakdown may occur at the voltage calculated on mechanism I the usually measured voltage will have a slightly higher value. Then in the transition region the measured voltage will be intermediate between that calculated on mechanisms I and II, the actual value of the voltage being subject to statistical variations. At the lower end of the transition region mechanism I will predominate, and as the gap length is increased the method of breakdown gradually changes over in a statistical manner to mechanism II. It is this statistical fluctuation which leads to the large scattering of voltage measurements observed in this region.

Calculations of the breakdown potential curves for spheres of different diameters have been made and give agreement within 2 or 3 per cent. of those experimentally observed. Since the experimental values given by many authorities do not themselves agree to much better than 2 per cent. it is considered that the theoretically determined values are as satisfactory as the present circumstances warrant.

THE EFFECT OF AIR DENSITY.

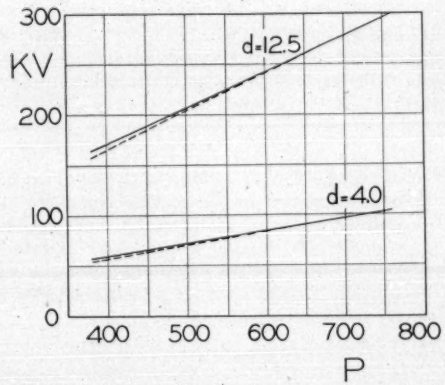
The variation of sparking potential with pressure for the uniform gap has been discussed in previous articles, where it is shown that equation (1) gives breakdown potentials in fair agreement with experiment for decreasing pressure down to a value of pressure times gap length of about 200 mm. Hg $\times$ cm. Calculations have now been made for the sphere gap and the resultant curves for two gap lengths between 12.5 cm. radius spheres for a pressure variation from 760 to 380 mm. Hg are given in Fig. 4. Reference to Fig. 3 shows that the chosen gap lengths of 4 cm. and 12.5 cm. fall into the regions I and II respectively.

A comparison with experiment is conveniently obtained by use of an empirical formula given by Peek [8] which is

[8] See ref. 2, page 125.

known to give an accurate representation of the experimental results over the range of pressure considered. This formula reads $V_p = V_{760} \cdot \sqrt{\delta} \left[\frac{\sqrt{\delta R} + 0.54}{\sqrt{R} + 0.54} \right]$, where V_p and V_{760} are the respective sparking potentials at pressures p and 760 mm. Hg, δ is the air density at p relative to that at 760 mm. Hg, and R cm. is the sphere radius. If one takes the breakdown potential at 760 mm. Hg as that calculated, which is known to be closely correct (as seen from the curves in Fig. 3), the ex-

FIG. 4.



The variation of breakdown potential with pressure (in mm. Hg) for a 12.5 cm. gap and a 4.0 cm. gap between spheres of 12.5 cm. radius. The experimentally observed variation is shown by the dashed curve.

perimentally observed variation of the sparking potential for the two gaps is given by the dashed curves in Fig. 4. There is seen to be close agreement between the degree of variation observed and that determined on the basis of the new theory, the difference being of the same order of magnitude as that to be expected between successive experimental observations.

THE TOEPLER DISCONTINUITY.

At certain low gap settings between spheres a slightly higher potential is required to cause breakdown between

spheres of small diameter than for larger spheres at the same gap setting. This phenomenon, now generally known as the Toepler discontinuity,[9] is frequently referred to in articles on sphere-gap breakdown though, to the writer's knowledge, there has as yet been no satisfactory explanation forthcoming. Such an explanation is now possible on the basis of the present theory, and will be found to be closely related to the region of transition between regions I and II to which reference has already been made.

The effect can be observed in the experimentally determined sparking potentials listed by a number of different workers.[1] However due to the smallness of the effect it is frequently masked by inaccuracies in measurement, while the lack of agreement between the measurements of different observers is of the same order of magnitude as the effect itself. In the calibration charts published by Edwards and Smee [1] the effect is noticed for a 7.5 cm. gap, when the breakdown voltages measured are given as 175, 194, 203, 200 kilovolts for spheres of radii 6.25, 12.5, 25 and 100 cm. respectively. The effect is more pronounced in the results given by Meador [1] for the breakdown voltage V_M of a 5.0 cm. gap between spheres of different radii, as given in the following table, where it will be seen that the breakdown voltage for the 12.5 cm. radius sphere gap is quoted as some 4.6 per cent. higher than that for the 25 cm. radius sphere-gap.

TABLE I.

R.	V_M.	V_I.	α_I.	V_{II}.	α_{II}.
25	130,000	130,500	2.5		
12.5	136,000	130,000	1.5	139,000	3.6
7.5		126,000	0.6	137,300	1.8
6.25	128,000	124,600	0.4	136,000	1.1
5.0		122,000	0.25	134,000	0.6
2.5				116,000	0.1

The corresponding calculated breakdown potentials are also given in the above table. V_I is the voltage determined on the basis that breakdown takes place according to region I,

[9] M. Toepler, *Elektrotechnische Zeitschrift*, **53**, 1219 (1932). W. Dattan, *Elektrotechnische Zeitschrift*, **57**, 377 (1936). J. Claussnitzer, *Elektrotechnische Zeitschrift*, **57**, 177 (1936).

while V_{II} is that determined on the region II basis. α_I and α_{II} are the respective values of α in the center of the gap that correspond to V_I and V_{II}. In the case of the spheres of 25 cm. radius the measured breakdown voltage is found to correspond to V_I, which is to be expected since the field distribution in the gap is fairly uniform. For the 12.5 cm. and 6.25 cm. radius spheres the measured voltage falls between V_I and V_{II}. This is the transition region, where the lack of uniformity of the field in the gap is such that the value of α in the center of the gap is very small, as seen by the values of α_I and α_{II} given in the table. For spheres of still smaller radius the breakdown procedure goes definitely over to the region II. However it should be recalled that the calculation of V_{II} is based on a symmetrical field distribution, which is not generally obtained in practice for spheres at spacings much larger than their radius. In general such voltage measurements are made with one sphere at high potential V while the second sphere is earthed. Such an arrangement leads to lower sparking potentials than that calculated where the voltages on the spheres are considered as $+\frac{V}{2}$ and $-\frac{V}{2}$ and the effect of objects external to the gap is neglected.

The Toepler discontinuity has further been studied in some detail by Claussnitzer,[9] who observed the effect for spheres of radii from 1 cm. to 50 cm. He gives values of the gap length at which the effect is observable, though the voltages are not quoted. These gap lengths d_K cm. are given in the following table.

TABLE 2.

R.	d_K.	V_M.	V_{II}.	V_I.	α_I.
5.0	3.65	101,000	101,000	95,000	0.8
12.5	7.15	190,000	191,000	177,000	0.6
25.0	11.0	285,000	280,000	261,000	0.4
50.0	17.0	430,000	420,000	398,000	0.5

At gap lengths of about 0.5 d_K he finds that the breakdown potential corresponds closely to that for the uniform gap. The breakdown voltage between 0.5 d_K and d_K is higher than that for the same gap length between spheres of much

larger diameter, the deviation being a maximum at about 0.8 d_K. For gap lengths greater than d_K the breakdown voltage is found to be less than for a more uniform field.

The interpretation of these observations is that region I obtains for gap lengths up to about 0.5 d_K, and that the transition to region II takes place between 0.5 d_K and d_K. Thus at d_K the breakdown mechanism should take place according to region II. That this is the case is borne out to some extent by comparison between the measured and calculated voltages for breakdown, as given in Table 2. The measured values V_M are those given by Hueter. It is seen that V_M is in close agreement with V_{II} and is much higher than V_I. The values of α_I are also included in Table 2 for interest, and show that this is the region of low mid-gap α when breakdown by mechanism II may be expected.

ACKNOWLEDGMENTS.

The writer wishes to express his appreciation to Professor L. B. Loeb who has been largely responsible for the development of the new theory of spark discharge and whose suggestions and criticism have contributed much to the completion of the present work. The opportunity afforded by the Commonwealth Fund in the grant of a Fellowship is most gratefully acknowledged.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

CORROSION OF AIRCRAFT METALS.

Investigations of the corrosion of aircraft metals have been in progress continuously at the Bureau since 1925. Approximately 25,000 specimens of aluminum alloys, magnesium alloys, and stainless steels (60 alloys in all) have been corroded by means of accelerated laboratory tests or by exposure to the weather or to sea water. The exposure localities were Washington, D. C., Hampton Roads, Va., and Coco Solo, Canal Zone. Corrosion was determined by means of loss in tensile properties, or was measured directly on cross-sections examined with the microscope at high magnification.

Corrosion in aluminum alloys occured as either the "pitting" or intercrystalline types. As shown in RP1316 by Willard Mutchler in the July *Journal of Research*, intercrystalline corrosion was responsible for serious embrittlement in duralumin-type alloys. Methods of heat treatment were evolved that eliminate intercrystalline attack. The work indicated that pitting could be minimized by preparing alloys from high purity components, and by keeping the copper and iron contents low. Binary magnesium-aluminum alloys were found to become more susceptible to corrosion as the aluminum content increased. Small additions of zinc or tin rendered these alloys more resistant to attack. Stainless steels of the 18 chromium—8 nickel type containing small additions of molybdenum were more corrosion-resistant than similar alloys without addition elements, or those with small additions of titanium or columbium.

Suitable surface coatings were developed, for both aluminum and magnesium alloys, to markedly improve their resistance to corrosion under severe saline conditions. The effect on corrosion produced by joining by means of rivets or by gas-welds, seam-welds, and spot-welds was determined. Important data were also obtained on the potential effects

* Communicated by the Director.

involved when alloys of different chemical compositions were exposed in contact with each other.

SECOND SPECTRUM OF VANADIUM.

Although discovered in 1831, by the Swedish chemist, Nils Gabriel Sefström, vanadium was not produced in a pure metallic state until nearly a century later. In 1932, the Vanadium Corporation of America supplied the Bureau with small ingots of pure vanadium metal for use as electrodes in spectrographic investigations. Four years later the Bureau published an extensive description and analysis of the spectrum emitted by neutral vanadium atoms. Now, in the July number of the *Journal of Research* (RP 1317), William F. Meggers, chief of the Bureau's Spectroscopy Section, and Charlotte E. Moore of Princeton University Observatory, present a new description of the spectrum emitted by singly ionized vanadium atoms, together with compilation and analysis of all available data. The second spectrum of vanadium is characterized by 1700 lines from red to extreme untraviolet, and 1456 of these are now explained as transitions between 89 identified atomic energy states. These facts are useful in the spectrochemical analysis of iron alloys containing vanadium. The presence of small amounts of vanadium profoundly alters the properties of steel, greatly increasing its toughness, elasticity and tensile strength. Thus the metal named for the ancient Swedish goddess of beauty, Vanadis, has come to play an important utilitarian rôle in the construction of locomotive frames, driving axles, turbine and generator shafts, and large gun barrels.

COMPOSITION OF CATHODE FILMS.

During electrodeposition the concentration of metal in the bath is lower within 0.012–0.020 inch of the cathode than in the body of the solution. Thus, the solution from which the metal is actually deposited has a composition which differs from that of the body of the bath. Although a knowledge of the composition and character of the cathode film would lead to a better understanding of cathodic processes, few attempts

have been made to study it directly. However, Abner Brenner at the Bureau has developed a new method for studying cathode films in which the latter is isolated by freezing on the outside of a hollow cylinder. The refrigerant, which is poured into the hollow cathode, is cooled with solid carbon dioxide.

The cylinder with its coating of frozen solution is then put on a lathe and successive layers, 0.003 to 0.005 in. thick, are turned off and analyzed. This method permits a direct measurement of the thickness of the cathode film and of the concentration gradient within it.

SPOT TEST FOR THICKNESS OF CHROMIUM COATINGS.

Chromium coatings over nickel deposits on such articles as automobile parts and plumbing fixtures are too thin to be measured by customary methods. The spot test is usually used, in which a measurement is made of the time required for one drop of concentrated hydrochloric acid to dissolve the coating. This method, with temperature corrections, is now prescribed in tentative specifications adopted by the American Electroplaters' Society and the American Society for Testing Materials.

W. Blum and W. A. Olson, in a paper prepared for the *Proceedings of the American Electroplaters' Society*, show that it is necessary to control closely not only the temperature but also the concentration of the hydrochloric acid. The use of 11.2 *N* HCl, having a specific gravity of 60°/60° F. of 1.180 is recommended, and a temperature-correction curve for that strength of acid has been plotted. With these precautions, the results are accurate to about 10 per cent.

DENTAL SILICATE CEMENT.

About 20 per cent. of all dental fillings are silicate cement, which is made by mixing a complex aluminosilicate powder containing calcium, sodium, fluorides, and phosphates with an aqueous solution of phosphoric acid containing zinc and aluminum salts. Results of an investigation conducted by the research associates of the American Dental Association at the Bureau on the physical and chemical properties of dental sili-

cate cements, together with a specification, were published in the January 1938 issue of the *Journal of the American Dental Association*. In order to assist in transferring these laboratory findings to dental practice, a series of 14 experiments was performed by a group of 115 dentists who were selected by the Research Commission of the Association. These experiments were designed to demonstrate the chemical and physical behavior of different brands of cement and the effect of technic of manipulation upon the serviceableness of the cements. A report of this investigation, which will appear in an early number of the *Journal of the American Dental Association*, presents the findings of the cooperating group of dentists on seven currently used brands of cement. The trade brand names of the cement are given throughout the report.

STABILITY OF FIBER BUILDING BOARDS.

The relative lasting qualities of fiber insulating boards have been studied as part of the investigation of materials for low-cost houses. Accelerated aging tests were used to produce effects similar to those arising from long periods of service.

Samples of the boards were subjected to wetting, drying, freezing, and baking in relatively rapid succession, and this treatment was supplemented by outdoor exposures made drastic by frequent wetting. Conclusions as to stability were based on relative resistance to the aging treatments and to the action of rot-producing fungi. In general, the retention under the aging treatments of the most essential properties of the boards—thermal conductivity and strength—was excellent. Furthermore, the fiber boards did not support the growth of rot-producing fungi except at relative humidities above 85 per cent. The growth at higher humidities was prevented, or at least appreciably retarded, by impregnating the boards with fungicides. The tests indicate, however, that these boards are not suitable for the exterior covering of buildings.

Results are given in detail in Building Materials and Structures Report BMS50, obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents a copy.

AIR INFILTRATION THROUGH WINDOWS.

The infiltration of cold air to the interior of a building through the clearance openings around movable members of windows and doors under the action of the wind may be an important factor in determining heating load requirements. Equipment for measuring the volume of infiltered air has been developed by Eugene F. Coleman and Roy H. Heald as a part of the investigation of materials and structures suitable for low-cost housing. Building Materials and Structures Report BMS45, which has just been released describes the equipment and methods used in making the infiltration measurements, and presents the results obtained for two types of windows frequently specified for low-cost construction. Copies are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

What Has Made Possible the 15,000 ft. Oil Well.—W. A. EARDLEY (*Mining and Metallurgy*, Vol. 21, No. 400). Fifteen years ago the world's deepest oil well penetrated the earth about 7,300 ft. That depth has now been more than doubled. Why has such deep drilling become necessary and how has it become possible? Three factors have had an important bearing: (1) Depletion of shallow zones, making it necessary to search for deeper producing measures. (2) The perfection of prospecting methods, which have been successfully used to locate favorable buried structures, many at great depth. (3) Improvement in the quality of steels used for drilling. The early oil wells in this country were drilled by the percussion, or cable-tool, method and from the time of the completion of Colonel Drake's discovery well in 1850 to about 1900 the depth of the wells ranged from 50 to 1,200 ft. With the turn of the century a new method of well drilling was introduced—the so-called rotary method, which is now used almost exclusively for oil-well drilling. Its principle, as the name suggests, is a cutting action produced by rotating the bit. With the rotary method the depths to which it has been feasible to drill have increased rapidly. In the year 1909 the world's deepest hole was 5,660 ft., in 1924 it was 7,319 ft., in 1934 it was 11,377 ft., in 1938 it was 15,004 ft.

R. H. O.

Tire "X-Ray."—(*Fleet Owner*, Vol. 24, No. 1.) A new fluoroscopic device which permits tire and service station attendants to x-ray tires on automobiles, has been developed by engineers of the General Electric X-Ray Corporation, Chicago, Ill. It is called the "Tire-O-Scope." Without removing the tire from the automobile, the operator of the device can by x-ray look into the tire to detect breaks, bruises, cord separations that are otherwise hidden, and such foreign objects as tacks, nails, wire, screws, glass and stones embedded in the casing. The unit is designed for inspection of tires on all types of passenger cars except large busses, and on some of the smaller trucks. The x-ray output is such that accurate inspection may be made of tires up to and including an eight-ply white side-wall tire. White side walls contain zinc oxide which renders them more opaque to x-radiation than the ordinary black walls. Only a single standard electric light outlet is required for operation of the unit which is equipped with rollers for easy movement about a station and from wheel to wheel of the car being inspected. A control device operated by a push button permits the operator to mark on the tire defects observed on the viewing screen as the wheel is turned slowly in the instrument.

R. H. O.

THE FRANKLIN INSTITUTE

MEDAL DAY MEETING.

Medal Day Exercises for 1940 were held at three-thirty o'clock on the afternoon of Wednesday, May fifteenth, in the Hall of the Institute. Dr. Philip C. Staples, President, presided.

He called upon Dr. Henry Butler Allen, Secretary and Director of The Franklin Institute, for a report upon the activities of the organization.

Dr. Allen stated, in part, that during the year the Institute had been guiding its members and friends, through a series of lectures, back to Benjamin Franklin: his calm reasoning, his homely virtues; and pointed out that these are much needed in the world today.

Dr. Allen deplored the fact that no awards for scientific achievement were being made to foreigners but pointed out that the omission had not been deliberate—rather, that it was the result of the occupation of scientists in other countries with pursuits not harbored in the peaceful atmosphere of the research laboratories.

At the conclusion of the Director's report, the President stated that the purpose of the Medal Day Meeting was the award of medals for distinction in the field of science, and stated that the Institute was proud to have the opportunity to honor so many Americans of genius He continued:

"I suppose the medalists would like to know something of the Committee which recommends the awards. The Committee on Science and the Arts has charge of selecting men, both from here and abroad, to be the recipients of our medals. The Committee, made up of members of The Franklin Institute, meets continuously. The Committee combs the field of distinguished men; it considers men of all nations, for the award of medals. Its research in the world of science is complete.

"It is a source of great pride to The Franklin Institute that men of comparative obscurity have been selected by our Committee to receive our awards. The Institute has many times been the first to recognize men who have gone on. It would seem that recognition from The Franklin Institute has led to signal honors from other organizations.

"You will see, from the programme, the gentlemen who have been recommended by the Committee on Science and the Arts to receive awards this year. Our Committee had proved its competency through one hundred years. It is possible that you gentlemen, who are about to be honored today, do not realize the distinction, the world renown, of the scientists who have preceded you. I should like to refer you to our records where you will be interested to read the names of outstanding medalists of other days.

"I hope these gentlemen who still survive are as proud of being on our distinguished lists of medalists as we are of the list. You are in the company, gentlemen, of very distinguished predecessors, and you add to the distinction of the list."

Dr. Staples, as presiding officer, then called upon the sponsors to present their medalists for the awards.

PRESENTATION OF THE CERTIFICATE OF MERIT.

In absentia to George H. Ernsbarger, Honolulu, T. H., and Frank Lee McCarty, Ogden, Utah. Mr. C. D. Galloway, Sponsor.

Dr. Staples: "The Chair recognizes Mr. Galloway."

Mr. Galloway: "Mr. President, the Board of Managers of The Franklin Institute, upon recommendation of its Committee on Science and the Arts, has awarded a Certificate of Merit to Messrs. George H. Ernsbarger and Frank Lee McCarty, 'in consideration of the development of a simple rugged and ingenious device for loading a jigging conveyor.' It was not possible for either gentleman to be present, so the award will have to be forwarded. The gentlemen have already expressed their appreciation by letter."

Dr. Staples: "Will the Secretary accept the award and forward it to the gentlemen named?"

Dr. Allen: "I shall see that the award is completed."

PRESENTATION OF LONGSTRETH MEDALS.

To Leopold Godowsky, Jr., and Leopold Damrosch Mannes, Eastman Kodak Company, Rochester, New York. Dr. George S. Crampton, Sponsor.

Dr. Staples: "Dr. Crampton."

Dr. Crampton: "The Board of Managers of The Franklin Institute, upon recommendation of its Committee on Science and the Arts, has voted a Longstreth Medal to Messrs. Leopold Godowsky, Jr., and Leopold Damrosch Mannes, consultants for the Eastman Kodak Company, 'in consideration of the ingenuity and inventive ability as shown in the development of Kodachrome Film and the processing thereof.' I have much pleasure in presenting Mr. Godowsky and Mr. Mannes."

Dr. Staples: "Gentlemen, by power vested in me as President of The Franklin Institute, I have the honor of presenting to you each an Edward Longstreth Medal."

Mr. Mannes: "I express my thanks for both of us. It is a distinction and a pleasure."

To Games Slayter, Vice-President, Owens-Corning Fiberglas Corporation, Newark, Ohio. Mr. Warren P. Valentine, Sponsor.

Dr. Staples: "I now call upon Mr. Valentine.

Mr. Valentine: "Mr. President, the Board has also voted a Longstreth Medal to Mr. Games Slayter, Vice-President, the Owens-Corning Fiberglas Corporation, Newark, Ohio, 'in consideration of his achievement in devising improved methods and apparatus for making spun and blown glass filaments.' I present Mr. Slayter."

Mr. Staples: "We are particularly gratified that you have come so far today to receive this medal, bestowed upon you by me by virtue of my office as President of The Franklin Institute."

Mr. Slayter: "For my organization and myself I wish to say I am deeply grateful."

To Richard L. Templin, Chief Engineer of Tests, Aluminum Company of America, New Kensington, Pennsylvania. Mr. W. H. Fulweiler, Sponsor.

Dr. Staples: "The next sponsor—Mr. Fulweiler."

Mr. Fulweiler: "Mr. President I have the honor to present to you Richard L. Templin, Chief Engineer of Tests, Aluminum Company of America, who has been voted a Longstreth Medal 'in consideration of the ingenious application of mechanisms resulting in the development of the Templin Automatic Autographic Deformation Recorder.'"

Dr. Staples: "By virtue of my office I have great satisfaction in presenting to you the Longstreth Medal and the certificate accompanying it."

Mr. Templin: "I wish not only to express my appreciation and satisfaction of the award but to acknowledge the assistance of my co-workers and to those who, above all, have brought the apparatus to its present state of usefulness."

To Maxwell Mayhew Upson, D. Eng., President, Raymond Concrete Pile Company, New York City. Mr. J. A. Vogleson, Sponsor.

Dr. Staples: "Mr. Vogleson."

Mr. Vogleson: "It is my privilege to sponsor the President of the Raymond Concrete Pile Company of New York City, to whom the Committee on Science and the Arts has recommended an award 'in consideration of his contributions to the scientific development of foundation engineering and construction, characterized by genius for invention and technical skill.' I present Dr. Maxwell Mayhew Upson."

Dr. Staples: "By virtue of my office I present to you the Longstreth Medal of The Franklin Institute and the certificate which accompanies the award."

Mr. Upson: "Mr. President, in accepting this mark of distinction I want to reiterate what has already been said. The President of a company does not accomplish everything himself. I thank you in behalf of myself and in behalf of those who have supported me."

PRESENTATION OF WETHERILL MEDALS.

To Laurens Hammond, President, Hammond Instrument Company, Chicago, Illinois. Dr. C. B. Bazzoni, Sponsor.

Dr. Staples: "The Chair recognizes Dr. Bazzoni."

Dr. Bazzoni: "Sir, I sponsor the award of the John Price Wetherill Medal, founded in 1925 by the family of that gentleman, to be awarded for discovery or invention in the

physical sciences or for new and important combinations of principles or methods already known. The Board of Managers sanctions this award to Laurens Hammond, President, Hammond Instrument Company, Chicago, Illinois, 'in consideration of the inventive skill displayed in the development of the Hammond Organ, a practical musical instrument for the production of tones of a wide range in pitch, intensity and quality, by electrical means; and for the combination and manipulation of these tones with the speed, certainty and flexibility demanded in the production of musical compositions.'"

Dr. Staples: "Music has a part in the work and enjoyment of The Franklin Institute, and even those who would be classified as laymen are conscious of the contribution you have made to the sphere of music. People like music and you have increased their joy of participation. By virtue of my office I hand you herewith the Wetherill Medal and the certificate accompanying it."

Mr. Hammond: "I deeply appreciate the honor. I am afraid that my contribution to the art of organ building has only been a minor one, and I cannot even play one!"

To Edward E. Kleinschmidt, President, Kleinschmidt Laboratories, Inc., Highland Park, Illinois, and Howard L. Krum, Beverly Hills, California. Mr. C. E. Bonine, Sponsor.

Dr. Stapes: "Mr Bonine."

Mr. Bonine: "A Wetherill Medal is also recommended for two gentlemen 'in consideration of their part in the development of a successful electrically operated duplicate typewriting machine now known as the teletypewriter.' I present Edward E. Kleinschmidt, President, Kleinschmidt Laboratories, Inc., of Highland Park, Illinois; and Howard L. Krum, of Beverly Hills, California, who has made a long journey in order to be with us today."

Dr. Staples: "You gentlemen have made long journeys to be with us and you are very welcome. Now if I may step from character for a moment I should like to say that, as a telephone man, I know something about teletypewriters; indeed, it butters some of my bread! It gives me the greatest satisfaction to hand you each a Wetherill Medal and the certificates which accompany the medals."

Mr. Krum: "Mr. Kleinschmidt and myself wish to thank you on behalf of ourselves and our co-workers."

PRESENTATION OF HENDERSON MEDAL.

To William E. Woodard, Vice-President in Charge of Design, Lima Locomotive Works, Inc., New York City, New York. Dr. R. Eksergian, Sponsor.

Dr. Staples: "The Henderson Medal, Dr. Eksergian."

Dr. Eksergian: "This award is made for distinguished contributions in the field of railway engineering and was founded in memory of George R. Henderson, for many years a devoted member of The Franklin Institute.

"The Committee feels the recipient this year is eminently fitted to receive it, 'in consideration of his accomplishments in locomotive engineering and his important contributions in the field of steam locomotive design'—William E. Woodard, Vice-President in Charge of Design, Lima Locomotive Works, Incorporated.

Dr. Staples: "Philadelphians feel particularly qualified to recognize a good locomotive man. We are delighted to honor you as a distinguished figure in that field."

Mr. Woodard: "I wish to thank The Franklin Institute for the high honor which it pays me in this award. It has a particularly personal angle to it. I knew Mr. Henderson well and I was very interested to come in contact with him many times. I came to have great admiration for his ability in his field, and also a great admiration for the high qualities of the man in whose memory this medal was founded."

PRESENTATION OF LEVY MEDAL.

To Charles Rosenblum, Ph.D., Instructur in Physical Chemistry, Princeton University, and John F. Flagg, Ph.D., Instructor in Chemistry, University of Rochester. Mr. Lionel F. Levy, Sponsor.

Dr. Staples: "The next sponsor represents the founders of the Medal to be presented."

Mr. Levy: "Mr. President, the Levy Medal was established to recognize papers of exceptional merit and interest that were published in the JOURNAL OF THE FRANKLIN INSTITUTE.

The paper selected this year deals with "Artificial Radioactive Indicators" and discusses methods whereby various chemical elements may be made radioactive. These elements may then be introduced into living systems and their progress through plant and animal traced by the rays given off by the radioactive element. This method has become an important research tool in biology. I present the authors—Dr. Charles Rosenblum, Instructor in Physical Chemistry, Princeton University, and Dr. John F. Flagg, Instructor in Chemistry, University of Rochester."

Dr. Staples: "Gentlemen, the JOURNAL OF THE FRANKLIN INSTITUTE is one of the bright jewels in its crown. It is always a pleasure to meet and to thank the contributors to that great scientific publication, so to Dr. Rosenblum and to Dr. Flagg I take great pleasure in presenting the Levy Medal."

Dr. Rosenblum: "Mr. President, both Dr. Flagg and I consider this award not so much to ourselves but as an award to the laboratories where the work was done. When the necessity for such a large work becomes apparent, then other work is apt to suffer somewhat; but because of the thoughtful coöperation and encouragement of our colleagues we were able to get the paper written. We feel, therefore, that the medal and the honor belong as well to our colleagues and our laboratories."

PRESENTATION OF CRESSON MEDALS.

To Frederick M. Becket, Sc.D., LL.D., Consultant, Union Carbide and Carbon Corporation, New York City. Dr. G. H. Clamer, Sponsor.

Dr. Staples: "We shall now have the award of the Cresson Medals. Dr. Clamer."

Dr. Clamer: "Mr. President, The Franklin Institute has been awarding the Cresson Medal since 1848. It is given for discovery or original research, adding to the sum of human knowledge, irrespective of commercial value.

I have the honor to present to you, for the Elliott Cresson Gold Medal, Dr. Frederick M. Becket, Consultant, Union Carbide and Carbon Corporation, New York City, who has

been chosen by the Committee on Science and the Arts, "in consideration of his outstanding achievements in the development of processes for the production of low carbon ferro alloys, which have led to the wide use of many of the now well-known alloy steels, particularly low carbon stainless steels, and the higher chromium oxidation-resistant steels; and also for his many inventions and contributions in the field of electrometallurgy." Dr. Becket.

Dr. Staples: "Because of the far reaching effects of your discoveries, and the wise application of them, it is eminently fitting that your name should be placed on the distinguished roll of scientists honored by The Franklin Institute. We welcome you to your deserved place on it."

Dr. Becket: "I thank you. It is with deepest appreciation that I receive this medal. All other medalists this afternoon have referred to their organizations and given them credit. Now I take this opportunity—and am very happy to have it—to express publicly my own gratitude to my fellow workers, many of them younger associates, who should share this honor with me."

To Robert R. Williams, D.Sc., Chemical Director, Bell Telephone Laboratories, Inc., New York City. Dr. J. S. Hepburn, Sponsor.

Dr. Staples: "Sponsor for another Cresson Medal—Dr. Hepburn."

Dr. Hepburn: "Mr. President, the Board of Managers of The Franklin Institute has voted the award of an Elliott Cresson Gold Medal also to Dr. Robert R. Williams, Chemical Director, Bell Telephone Laboratories, Inc., New York City, 'in consideration of his researches upon vitamin B_1, including its isolation in the pure state in quantity sufficient for further chemical study, the identification of its segments, and its synthesis in quantity.' These researches have covered a period of over three decades and I consider it a pleasure and a privilege to be the sponsor for a man who is to receive this high honor, the oldest in the gift of the Institute."

Dr. Staples: "Dr. Williams, by virtue of my office as President of The Franklin Institute, I bestow upon you the Elliott Cresson Medal. And, quite off the record, and as one telephone man to another, may I congratulate you heartily upon this honor."

Dr. Williams: Mr. President, in view of the Secretary's reference to world events, it is peculiarly appropriate for me to call attention to the Dutch contribution to the field of my interest. It was the Dutchman, Eijkman, thirty years later honored by the Nobel prize, who first produced beriberi in experimental animals in 1896 and with his successor, Grijns, proved it a dietary deficiency disease. Their work laid the foundation of the vitamin doctrine and led directly to the discovery of other vitamins. Further, it was two later Dutchmen, Jansen and Donath, working in the same laboratory in Batavia, who first isolated the beriberi vitamin in pure form in 1926.

In expressing my thanks for this generous award, I simply want to point out that much of what we have learned about dietary disease, and particularly the success which has been attributed to me, stems from Dutch scientific research in the East Indies.

PRESENTATION OF THE FRANKLIN MEDALS.

To Arthur Holly Compton, Ph.D., Sc.D., LL.D., in absentia.

Dr. Staples: "The Chair recognizes Dr. Frederick Palmer who will present the Franklin Medalists."

Dr. Palmer: "Mr. President:

The Board of Managers of the Franklin Institute, upon the recommendation of its Committee on Science and the Arts, is unanimously of the opinion that two Franklin Medals be awarded this year. One to—

DR. ARTHUR HOLLY COMPTON,

Professor of Physics at the University of Chicago,

"In recognition of his brilliant experiments on various properties of X-rays, some of which involved new methods of attack, and, in particular for his discovery and theoretical treatment of the Compton Effect."

Dr. Arthur H. Compton graduated from the College of Wooster in 1913. In 1916 he received the degree of Ph.D. from Princeton University. Only seven years later he was

appointed Professor of Physics at the University of Chicago. He has been the recipient of many honors and awards, including the Nobel Prize in Physics in 1927.

Dr. Compton's early work on the total reflection of X-rays incident upon a metallic surface at a very small angle led to a new method of measuring the wave-length of X-rays, namely the ruled grating method, the results of which are now regarded as more exact than those obtained by the earlier crystal method of Bragg,—results from which have been calculated more reliable values of fundamental physical constants.

In 1923 Dr. Compton investigated the nature of X-rays which had been scattered by matter. For such scattered rays the old electro-magnetic theory predicted no change of wave-length, whereas the new quantum theory predicted a modification in wave-length. Dr. Compton's photographs showed the existence of both types of ray. He explained the modified wave-length as due to a collision of an X-ray photon with a free electron, the photon bouncing off in one direction with a changed wave-length and the electron recoiling in an opposite direction. Application of the quantum theory led to equations which checked with experiment. Thus Dr. Compton not only discovered a new phenomenon, which now bears his name, but also gave its correct theoretical interpretation,—a dual feat of great brilliance.

For the past ten years Dr. Compton's chief work has been in the field of Cosmic Rays. From his world wide survey in 1933 he concluded that these rays are largely composed of enormously energetic electrified particles. Other cosmic ray problems still engage his attention.

Mr. President, I express on behalf of all of us our keen regret that, due to lecture engagements in the west, Dr. Arthur H. Compton is unable to be present to receive this award to-day. We are, however, honored by the presence of his brother, President Karl T. Compton, of the Massachusetts Institute of Technology, who will receive the Franklin Medal for him and read his address. It gives me pleasure, Sir, to present—

President Compton."

Dr. Staples: "What a pity it is that Dr. Arthur Compton cannot be here today, but how delightful that we can have as our guest and his representative his very distinguished brother—Dr. Karl Compton, President, Massachusetts Institute Technology, to whom we are greatly indebted for his kindness in taking the long trip to be here. I place in his hands the Franklin Medal, the Certificate and the Certificate of Honorary Membership in The Franklin Institute which it has been our great pleasure to confer upon Dr. Arthur Compton."

In receiving the Medal and Certificates from Dr. Staples, Dr. Compton said: "I deem it a great pleasure to accept this medal on behalf of my brother. When I saw him last he asked me to express his very sincere regret that his previous engagement, made long ago, to give a series of lectures at the University of Washington at Seattle, made it impossible for him to be here today.

"In his name I wish to express appreciation and his gratitude to his college and to his colleagues who have worked with him.

"I have here a paper, prepared by my brother, which he has sent to me to be read here today. The title is 'What We have Learned From Scattered X-Rays.'" *

To Leo Hendrik Baekeland, D.Nat.Sc., D.Ch.S.Sc., LL.D., President (Retired), Bakelite Corporation, New York City, New York.

Dr. Staples: "Dr. Palmer."

Dr. Palmer: "Mr. President:

The other Franklin Medal to

DR. LEO HENDRIK BAEKELAND
of New York City,

Retired President of the Bakelite Corporation,

"In recognition of his inventions and his contributions to the improvement of the industrial arts, and, in particular, of his invention and manufacture of the synthetic product, Bakelite."

* See page 149.

Of the many prizes and medals which Dr. Baekeland has received, the one which influenced his subsequent scientific career the most was the gold medal and prize awarded to him at the age of twenty-six by representatives of the four universities of his native country, Belgium. This prize enabled him to come to the United States and continue his study of the properties of photographic papers, with the result that in a few years he put on the market the popular product known as "Velox" paper.

Dr. Baekeland's most important work has been in connection with the chemical reaction between carbolic acid and formaldehyde. By heating the product of this reaction under pressure he turned the viscous mass into an insoluble solid, with an appearance like amber or ivory, which cannot be melted again, is easy to mold, is resistant to moisture and to chemical reagents, and does not conduct electricity. This synthetic resinous substance was called "Bakelite." Last year it was reported that the production of bakelite was more than one million pounds per week. The number of industrial applications of this invention are to-day legion, and new uses for it are continually being found.

Mr. President, I have the honor and the pleasure of presenting to you for the award of a Franklin Medal the inventor of bakelite,

Dr. Leo Hendrik Baekeland."

Dr. Staples: "Dr. Baekeland, by power vested in me as President of The Franklin Institute, I have the honor to confer upon you this Franklin Medal and Certificate of Honorary Membership. The Institute is proud and honored to add your illustrious name to its rolls."

Dr. Baekeland in receiving the Medal said: "After seeing, and hearing about, the wonderful work which is being done by engineers and chemists and physicists, I feel that my little work is small indeed by comparison. It was suggested to me that today I might tell you a little about my contributions, so therefore I should like to give you a brief resumé of my work." *

At the conclusion of the papers, Dr. Staples expressed the warm appreciation of the officials to those who had

* See page 159.

attended the exercises and stated that he hoped those who were present in the afternoon would attend the dinner in the evening as well. The meeting then adjourned.

MEDAL DAY DINNER.

A dinner at which the Medalists of the afternoon were the guests of honor, was held at seven-thirty in Franklin Hall in The Franklin Institute. About three hundred guests were present.

The programme following the dinner was as follows:

DR. PHILIP C. STAPLES, *President*, Presiding

1. Introduction of Medalists.....THE PRESIDENT
2. "How I Happened to Select Synthetic Resins as the Object of Further Research". DR. LEO H. BAEKELAND
3. "Birth and Growth in Science and Industry: an Analogy to Nature's Laws"...DR. KARL COMPTON
4. "The Franklin Institute: Changing Service with Changing Times".....HENRY BUTLER ALLEN *Secretary and Director*
5. "Bakelite" Plastics Demonstration. DR. NICOL H. SMITH *Associate Director in Charge of Chemistry*, The Franklin Institute

---

LIBRARY NOTES.

The Committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 8½ × 11 inches is forty cents.

The library and reading room are open daily from nine o'clock A.M. until five o'clock P.M. Saturdays until 12 o'clock noon. 589 readers made use of the facilities during the twenty-five days of June.

RECENT ADDITIONS.

AERONAUTICS.

Aircraft Year Book for 1940.

BIOGRAPHY.

KENDALL, JAMES. Young Chemists and Great Discoveries. 1939.

Who's Who in America. Volume 21, 1940–1941. Two Years. 1940.

BIOLOGY AND BIOCHEMISTRY.

Annual Review of Biochemistry. Volume 9. 1940.
Ergebnisse der Vitamin-und Hormonforschung. Band 1. 1938.

CHEMISTRY AND CHEMICAL TECHNOLOGY.

DORSEY, N. ERNEST. Properties of Ordinary Water-Substance. 1940. American Chemical Society. Monograph Series. No. 81.
Society of Chemical Industry. Chemical Engineering Group. Proceedings. Volume 21. 1939.

ENGINEERING.

DELMONTE, J. Plastics in Engineering. First Edition. 1940.
Engineering Index. 1939.
KÁRMÁN, THEODORE V., AND MAURICE A. BIOT. Mathematical Methods in Engineering. First Edition. 1940.
LARSON, ERICK. Pipe Corrosion and Coatings. First Edition. 1938.
PLUMMER, FRED L., AND STANLEY M. DORE. Soil Mechanics and Foundations. 1940.

GEOLOGY.

Great Britain. Imperial Institute. The Mineral Industry of the British Empire and Foreign Countries: Lead. Second Edition. 1933.

MANUFACTURES.

JONES, F. HOPE—. Electrical Timekeeping. 1940.

PHARMACY AND HYGIENE.

Pharmacopœia of the United States of America. Eleventh Decennial Revision. First and Second Supplements. 1937–1939.
STONE, GILBERT. Laws and Regulations Relating to Lead Poisoning. 1922. Great Britain. Imperial Mineral Resources Bureau.

PHOTOGRAPHY.

QUARLES, GILFORD G. Elementary Photography. First Edition. 1940.

PHYSICS.

EGLOFF, GUSTAV. Physical Constants of Hydrocarbons. Volume 2, 1940. American Chemical Society. Monograph Series No. 78.
LINDSAY, ROBERT BRUCE. General Physics. 1940.
SVEDBERG, THE, AND KAI O. PEDERSEN. The Ultracentrifuge. 1940.
WILSON, W. Theoretical Physics. Volume 3, 1940.

PRINTING.

MCCLINTOCK, MARSHALL. Here is a Book. 1939.

SANITARY ENGINEERING.

American Water Works Association. Index to the Proceedings, Journal, and Other Publications, 1881–1939, Inclusive. 1940.

SCIENTIFIC ESSAYS.

TAYLOR, F. SHERWOOD. Science Front 1939.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Excitation and Detection of Ultraviolet Fluorescence.—R. G. FRANKLIN AND A. J. ALLEN. A rather extended search was made for a non-toxic soluble compound which under X-rays would fluoresce in the lethal range of the ultraviolet spectrum, preferably at 2600 A.U. or less. Such a compound was desired in order to investigate whether the effect of X-radiation on tumor tissue might be enhanced by its injection into the tumor. Since fluorescence is presumably a property of the molecule or of a molecular aggregate, it should vary with the source of excitation in intensity rather than in quality. It was found that the fluorescence excited by X-rays was extremely weak and in the majority of cases imperceptible, while that excited by cathode rays or ultraviolet light was much more intense and easily detected. Preliminary investigations were therefore made with cathode rays or with ultraviolet light as the exciting source of radiation, and only the more promising compounds were examined with X-rays.

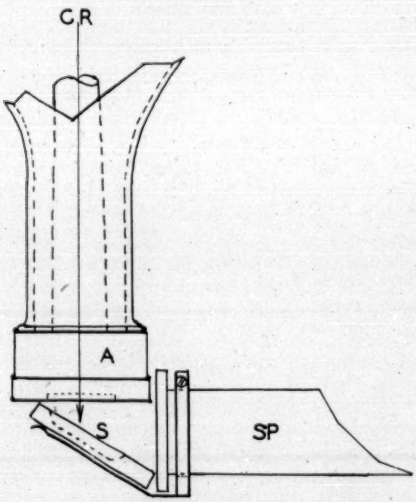
Methods. In these routine examinations it was convenient to arrange the apparatus so that solids were examined under cathode radiation and liquids and solutions under ultraviolet light. However, as a check on the methods, or when desired for other reasons, determinations on both solids and solutions were made with both sources of radiation.

A. Cathode Rays.

The anode of a cathode ray tube (125 k.v. maximum voltage) was held at ground potential. A thin water-cooled aluminum window sealed to the end of the anode with wax served as an exit for the cathode rays. The sample to be tested was placed in a suitable holder and attached to a Hilger E31 quartz spectrograph in front of the slit as shown in Fig. 1. When the sample was placed in the cathode beam, the fluorescent light entered the slit and was recorded on a photographic plate. In the case of liquids small glass receptacles were used, held in a horizontal position. The

spectrograph was then turned so that the light from the surface could enter the slit.

FIG. 1.



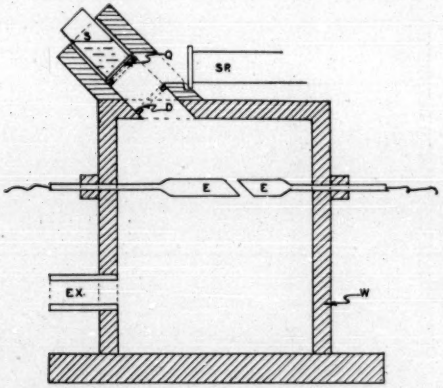
Detection of fluorescence under cathode ray excitation. *CR*—cathode ray beam; *A*—anode; *Sp*—spectrograph; *S*—sample.

B. Ultraviolet Light.

The solution to be examined was held in a quartz tube with an optically flat bottom or a glass tube with a quartz window sealed onto the end. Light from a suitable source was allowed to fall on the window at an angle of 90°, thus preventing reflected light from entering the spectrograph (see Fig. 2). A condensed spark between cadmium electrodes was found convenient, since the Cd-spectrum has several strong lines in the far ultraviolet region which would therefore be capable of exciting fluorescence in the desired range. The fluorescent light is brightest at the point of incidence of the light, that is, at the window. With the spectrograph in the position shown in Fig. 2 the fluorescent light can be

photographed without passing through the solution and suffering absorption. An exhaust carried the CdO fumes away and prevented the formation of a film on the quartz window.

FIG. 2.



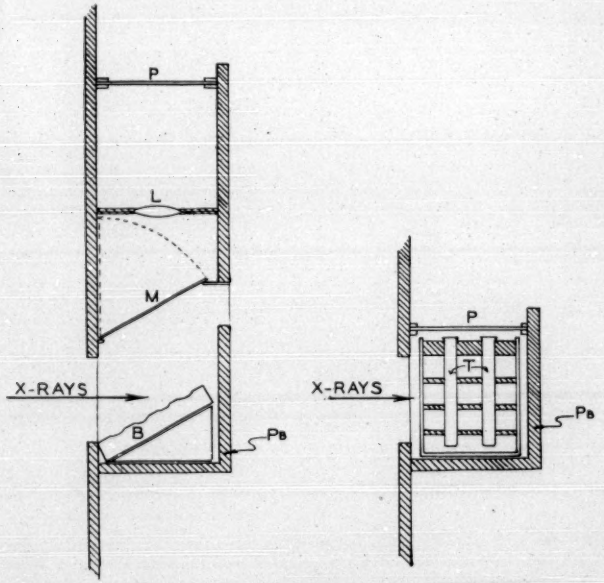
Detection of fluorescence under ultraviolet light. *S*—solution; *Q*—quartz window; *Sp*—spectrograph; *D*—diaphragms; *E*—electrodes; *W*—wooden box; *Ex*—exhaust.

C. X-Rays.

For the excitation of fluorescence by X-rays a 220 k.v. kenetron rectified X-ray apparatus was used running at approximately 160 k.v. and 4 ma. A window through which the X-rays passed was cut in the protecting lead box. Visible light was excluded by a cardboard placed over the opening. The samples to be tested (24 at a time) were placed in depressions bored in a wooden block *B* (see Fig. 3*a*) and placed in the X-ray beam as shown. Calcium tungstate paste, which fluoresces brightly under X-rays, was made by mixing the solid calcium tungstate with water and a bit was used to mark each sample. The fluorescent light was focussed by a quartz lens system on the photographic plate at *P*. Visual examination could also be made by interposing a mirror *M*. The whole was enclosed in a light-tight box with suitable lead

protection. If blackening was detected on the photographic plate when no light was seen visually, or if it appeared to be stronger than the visual examination indicated, it was assumed that the fluorescent light was in the ultraviolet

FIG. 3a. FIG. 3b.



3a. Detection of fluorescence of solids under X-ray excitation. *P*—photographic plate; *L*—quartz lens; *M*—mirror; *B*—wooden block for holding samples; *Pb*—lead protecting box.
3b. Detection of fluorescence of solutions under X-ray excitation. *P*—photographic plate; *T*—aluminum tubes to hold samples; *Pb*—lead protecting box.

region and further tests were made. In some cases it was examined spectrographically with the Hilger E31 quartz spectrograph under X-rays. When liquids were tested, aluminum tubes were used as shown in Fig. 3*b* and the light generated in the whole length of the tube photographed. In this case the quartz lens was not used, the photographic

plate being placed directly above the tubes. To cut down scattered radiation, several lead diaphragms were introduced as shown in Fig. 3*b*. A piece of paper (not shown) cut to cover half of each tube was placed between the top of the tubes and the photographic plate. This served as a further check on scattered radiation, as it absorbed the fluorescent light but not the scattered X-rays. A comparison of the photograph of the two halves of the tube indicated the amount of blackening due to the fluorescence.

Results. Approximately 1600 compounds belonging to the following chemical types were tested in the manner described.

Aromatic Compounds: benzene, polycyclic hydrocarbons, aldehydes, ketones, ethers, quinones, azo compounds, and certain of their acid, halogen, alkyl, amino, nitro, nitroso, sulfonated and hydroxy derivatives.

Aliphatic Compounds: saturated and unsaturated hydrocarbons, aldehydes, ethers, and certain of their acid, halogen, amino, hydroxy and keto derivatives; also a few cyclic paraffin derivatives and amidines.

Heterocyclic Compounds: pyridines, pyrroles, quinolines, furanes, pyrimidines, purines, thiazoles, carbazoles and acridenes.

Miscellaneous Compounds: some dyes, alkaloids, carbohydrates, proteins, amino acids, and a few organo-metallic compounds.

Inorganic Compounds: approximately 150 inorganic salts, including metal salts of common organic acids.

From the data obtained a few general conclusions may be reached.

1. Aromatic compounds fluoresce much more strongly both as solids and in solution than do the aliphatic compounds.

2. Many inorganic salts fluoresce in the solid form but not in solution.

3. In each group the lower wave-length limit of fluorescence is set by the unsubstituted member. Added radicals lengthen this wave-length limit. Following are the observed lower limits of the fluorescent light emitted by some of the compounds.

Benzene	2650 A.U.	Pyrrole	3100 A.U.
Naphthalene	3100	Quinoline	3900

Anthracene	4200	Carbazole	3500 A.U.
Diphenyl	3200	Hexane	2300
Triphenyl carbinol	2800	Methyl alcohol	2700
Pyridine	3100	Paraffin oil	2750
Furane	3100	Sodium bromide	2400

4. Certain radicals such as SO_3H, OH, COOH, intensify the fluorescence while others, like NO, NO_2, tend to quench it.

5. In general, the short wave-length limit of the fluorescent light corresponds to the long wave-length limit of the absorption band. However, in some cases it was possible to detect fluorescence within the absorption band, indicating that fluorescent light may be generated in the solution and subsequently reabsorbed.

6. As mentioned above, the fluorescence excited by X-rays is weak compared to that excited by cathode rays or ultraviolet light. This may be due to the greater absorption of incident energy, especially at the surface, when using cathode rays or ultraviolet light, whereas little of the X-ray energy is absorbed. Fluorescence was observed in many types of compounds under ultraviolet light or under cathode rays, but comparatively few compounds fluoresced under X-rays. Of those tested the following gave positive results under X-rays.

Solids: derivatives of benzene, especially the sulfonates, naphthalene and its derivatives, especially its sulfonates, diphenyl and triphenyl compounds; inorganic salts, particularly calcium tungstate and sodium bromide and chloride.

Liquids: aqueous solutions of disodium naphthalene-1, 5-disulfonate, disodium 2-naphthol-6, 8-disulfonate, sodium beta-naphthalenesulfonate. Nujol (commercial) also fluoresced under X-rays.

7. The fluorescent light emitted by these compounds in the lethal range of the spectrum is so weak, however, that it was felt that this was not a practical method of increasing the effect of X-radiation on tumor tissue.

A complete list of the chemicals tested in this work with the data obtained is on file in the library of the Biochemical Research Foundation of the Franklin Institute.

A Numerical System Using Colors for Marking Albino Rats and Mice.—JANETTA SCHOONOVER DOHAN (*Journal of Laboratory and Clinical Medicine*, **25**: 872, 1940). A system of color marking employed recently in the animal room of the Biochemical Research Foundation combines the advantages of a numerical system with those of color technique.

Nine different locations on the animal represent the digits from 1 to 9: left ear = 1, right ear = 2, left shoulder = 3, back of neck = 4, right shoulder = 5, middle of back = 6, left hip = 7, lower back = 8, right hip = 9, no mark at all = 0. Four colors, yellow, red, green, and purple, show whether the digits belong in the ones, tens, hundreds, or thousands column, respectively, and can be produced by painting with solutions of picric acid, carbol-fuchsin, malachite green and gentian violet, none of which has been found to be poisonous to the animals. A number in which the same digit occurs more than once (55, 1232, etc.) cannot be represented.

Example of application: purple on lower back, no green mark, red on middle of back and yellow on left shoulder designates an animal as No. 8063.

Studies on Capsule Formation. II. The Influence of Electrolytes on Capsule Formation by Klebsiella pneumoniæ.—J. C. HOOGERHEIDE (*Journal of Bacteriology*, **39**: 649, 1940). From a colloid-chemical point of view, a culture of bacteria which possess large capsules may be considered a suspension of small hydrophilic gel particles of polysaccharide nature suspended in a medium which itself is very poor in colloids. Therefore, it seems reasonable to assume that rules which have been found to be valid for similar hydrophilic gel suspensions will apply also, to a certain extent, for suspensions of encapsulated bacteria.

In agreement with the results obtained by several investigators with pure hydrophilic gel or sol solutions, it was found that the viscosity of full-grown cultures of encapsulated Friedländer's bacterium dropped considerably upon the addition of small amounts of electrolytes. With increasing amounts of electrolytes the viscosity decreased until a level was reached, where, upon further addition of electrolyte, no

further decrease took place. All monovalent cations behaved identically. Bivalent cations were more effective in equivalent concentrations than monovalent cations, but ultimately, with higher concentrations, the same level was reached with monovalent as with bivalent cations.

These facts suggest that addition of electrolyte to full-grown cultures of encapsulated Friedländer's bacterium eliminates a negative charge of the bacteria and thus causes a decrease in the relative viscosity.

A completely different picture was observed when electrolytes were added to culture media in which Friedländer's bacteria were allowed to grow. All of the electrolytes which could be added in sufficient concentrations without inhibiting growth, strongly inhibited the formation of capsules.

When, however, electrolytes were added in equivalent concentrations it was found that the inhibition increased with the molecular weight of the cations used, e.g., $Mg^{++} < Ca^{++} < Sr^{++} < Ba^{++}$. Similarly, "lyotrophic series" were found when salts having monovalent cations or when the sodium salts of different anions, $\frac{1}{2}SO_4^{--} < Cl^- < CNS^- < NO_3^-$, were used.

Since inhibition of encapsulation is therefore non-specific and can be brought about by a great variety of electrolytes, is there a common factor which might explain this inhibitory effect? It has been shown that adsorption of electrolytes on surfaces in general also follows these three lyotrophic series. It is therefore probable that adsorption of electrolytes (presumably on the enzymes responsible for the synthesis of bacterial polysaccharides) is sufficient to inhibit the formation of these capsular polysaccharides.

BOOK REVIEWS.

PROPERTIES OF ORDINARY WATER-SUBSTANCE, by N. Ernest Dorsey. 673 pages, illustrations, tables, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1940. Price $15.00.

This American Chemical Society Monograph is similar in construction to others in this series. It covers information regarding the properties of pure, ordinary water substance in all its phases—water vapor, water, and the several ices—and regarding the phenomena and data pertaining to its synthesis and dissociation and to its transition from phase to phase. The effect of the presence of air is considered, as are also the solubilities and diffusivities in water of the atmosphere and noble gases, of hydrogen, ozone, carbon monoxide, and ammonia, and the diffusion of water vapor in air, hydrogen, and carbon dioxide, and through a few solids. The coverage includes some types of information that might not be expected in such a compilation. Examples of these are the preparation of dust free water and of monocrystals of ice, the color of water and of the sea, and the volumes of water menisci.

The arrangement of this material is in five broad groups: (I) Synthesis and dissociation: (II) Single phase systems, subdivided into (IIa) Water vapor, (IIb) Water, (IIc) Ice; (III) Multiple phase systems; (IV) Phase transition; and (V) Miscellanea. Each of these is subdivided into smaller units, devoted to a closely related group of data or phenomena and the arrangement here is according to the nature of the phenomena and in the following order: atomic or molecular, mechanical, acoustic, thermal, optical, electrical and magnetic.

The compiler states that he hopes that no important article bearing upon the subject and appearing before 1938 has been overlooked; but only the most important of those appearing after June 30, 1937 and coming to the compiler's attention, have been considered. In accordance with the initial plan, the International Critical Tables has as far as possible been depended upon for information antedating Jan. 1, 1923, and the compiler himself has searched journals from 1922 to 1938.

There is a very great amount of data given in this book and it is all so arranged as to be easily located. The compiler is to be congratulated on the completion of this difficult task, the value of which is beyond any method of measurement. The work is typical of the monograph series of the American Chemical Society and is destined to give impetus to activities in this field.

R. H. OPPERMANN.

PHYSICAL CONSTANTS OF HYDROCARBONS. Volume II, Cyclanes, Cyclenes, Cyclynes, and other Alicyclic Hydrocarbons, by Gustav Egloff. 608 pages, illustrations, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1940. Price $12.00.

The July 1939 number of the JOURNAL OF THE FRANKLIN INSTITUTE contains mention of Volume one of this series of books. Volume two has now made its

appearance and it covers cyclanes, cyclenes, cyclynes and other alicyclic hydrocarbons. The general method of arrangement of Volume one is adopted here and the same thoroughness is practiced.

At the beginning there is a discussion on the theory of structural configurations and an explanation of the rules for naming compounds. The author makes note of the difficulty of critically evaluating the experimental data which has been complicated by numerous investigators who have not reported probable errors of their physical constants; nor have they given sufficient details of their experiments to enable evaluation of constants with the degree of accuracy comparable to Volume one on aliphatic hydrocarbons. Since there is no one method by which the probable errors can be calculated from the alicyclic constants, an estimate has been made of the probable degree of reliability by consideration of the mode of synthesis, purification, and measurements. Just how this is done is explained for each of the following; melting points, boiling points, specific gravity, and index of refraction.

This set of books is to consist of four volumes. Completion of the one at hand marks the half way point of the work. It is an American Chemical Society monograph and a contribution of great value to workers having use for the wealth of material it contains.

R. H. OPPERMANN.

SCIENCE FRONT, 1939, by F. Sherwood Taylor. 301 pages, plates, illustrations, 13 × 19 cms. New York, The Macmillan Company. Price $2.50.

Discoveries and developments in science are becoming so numerous and are reaching the stage of practical application so often that it is increasingly difficult for the person who seeks to keep well informed to follow them. The field of these activities is also widening to the extent that things seem to happen over night. Broad as this frontal attack on the unknown may be, there are certain activities that demand attention more than others and it is to these that the author of this book addresses himself in an effort to inform the person of average intelligence just what has been going on in the few years ending with 1939. In doing this, the assumption is made that the reader has a knowledge of chemistry and physics, but actually much can be obtained without it. Some of the subjects covered are science and plant growth, progress in chemotherapy, the war against cancer, the making of oil from coal, progress in television, the new quartz clock, and our view of the universe.

Photographs and drawings supplement the descriptive matter. The presentation makes easy reading. It is informative without being sugar coated. The author seems to know just what to stress and where to stop for the lay mind. And the selection of subjects is not one of mere spectacular achievements but one of careful consideration. Anyone, desirous of keeping informed of the progress of science will find here a very helpful book.

R. H. OPPERMANN.

ELEMENTARY PHOTOGRAPHY, by Gilford G. Quarles. 350 pages, illustrations, plates, 16 × 24 cms. New York, McGraw-Hill Book Company, Inc., 1940. Price $3.00.

Photography today is very popular among a great number of people and it is destined to become an interesting hobby and pleasure to countless thousands

more. The new materials, devices, and methods developed in recent years have made so much more possible that almost over night this hobby became widespread. Among those who pursue it can be found the beginners to whom even the fundamentals are strange. Then there are those more advanced who have reached the satisfying stage of obtaining a likeness of loved ones or familiar objects or have succeeded in being proficient in making correct photographs that convey pertinent information. The highest type of photographer is he to whom photography is a scientific art, the means not only of recording passing events, but of making pictures of artistic merit to afford boundless pleasure both to himself and to those who view them.

This book is aimed to be helpful to all groups and it is so arranged that all can use it either as a text or for reference. After a brief introduction and a historical account of photography the treatment starts with elementary photographic optics in an effort to secure a thorough grounding in the fundamentals of the technical side of the subject. Subsequent subjects are aberrations in lenses, camera parts and accessories, cameras and camera testing. The necessity for correct exposure in order to get a rendition of tonal values of the subject is discussed, and the methods of development of negatives and the effect of the amount of development on the appearance of the negative. The rest of the work deals with those phases of the subject leading toward not only the technically perfect photograph but the artistically satisfying one. There is considered what makes for beauty in a photograph and how to secure a beautiful effect. Here there is taken into account enlargements, projection control, the selective printing of various parts of a picture, retouching and mounting of finished prints, making pictures with paper negatives, lantern slides, etc. Natural color photography is approached through consideration of toning and hand coloring, and then the theory and practice of some natural color processes are studied.

The book adequately fulfills its purpose. The method of presentation is such that the contents are easily understood by the beginner and the sequence allows for picking up the thread of progression by those who are already versed in fundamentals. The author places emphasis throughout on care, neatness, and cleanliness in every phase of the work. The book is one that amateurs can use with profit, not only from the standpoint of paving the way for greater achievement but in pointing out methods and techniques that experience has already shown to be of value.

R. H. OPPERMANN.

LIVING LIGHT, by E. Newton Harvey. 328 pages, illustrations, plates, 16 × 24 cms. Princeton, Princeton University Press, 1940. Price $4.00.

Animal light has interested man through the ages. The emission of light by living things is a chemical reaction requiring oxygen. Many luminescent creatures secrete an easily oxidizable compound, luciferin, which is oxidized with the help of an enzyme, luciferase. The exact chemical nature of luciferin and luciferase varies from species to species. As a necessary adjunct to living in a world of darkness, nature has given to some lowly creatures a means of producing light that far transcends in simplicity the elaborate facilities of man's lighting utilities.

Man's scientific achievement is challenged by the accomplishments of the firefly and the glow-worm.

The subject of luminescence is not only holding prominent scientific attention but has moved to the forefront of commercial and popular interest. It is noteworthy that the last two decades have witnessed a rapidly increasing use for all kinds of cold light—luminous paints; fluorescent screens for television; and new types of glow lamps and fluorescent lamps for illumination.

This revolution in lighting has turned us from incandescence to luminescence —the method of the firefly.

The great importance of materials exhibiting phosphorescence and fluorescence for use in the manufacture of television screens and in modern illumination have led to increased investigation of the subject.

Phosphorescence is a term that has been loosely used to indicate all kinds of luminescence and particularly that of phosphorus and luminous animals. To the physicist this word has a very definite meaning—namely the absorption of radiant energy by substances which afterwards give it off as light. If the material gives it off for less than a millionth of a second after being radiated we speak of fluorescence.

Curiously enough red and infrared rays have the power to annul phosphorescence by greatly accelerating the rate of decay. Ives, in 1910, showed that infrared radiation had no power of quenching the light of the firefly—an observation cited to demonstrate that the firefly's light is not due to phosphorescence.

Harvey's numerous original papers have been chiefly in the field of bioluminescence. In this important new book a distinguished scientist displays an exceptional talent not only for searching investigation on his own account but also in bringing together the discoveries of other workers in this field.

"Living Light" is especially timely at this moment when the incandescent filament lamp seems to be going the way of the old-fashioned gas light and Welsbach mantle.

Dr. Harvey's book opens with a chapter on "Cold Light" in general—then examines the many different types of luminescence, indicating those which are involved in the emission of living light and in what way they are produced. Then come chapters dealing with light-producing organisms, which are described in considerable detail; the chemistry of light production; the physiology of light production and the physical nature of animal light. In the last chapter are data (which hold particular interest for physicists and illuminating engineers)—regarding the intensity, quality and efficiency of animal light. Dr. Harvey reports in this book on his quarter-century of tireless investigation in one of the most fascinating fields of modern science.

The Franklin Institute bestowed upon Dr. Harvey the Wetherill Medal in 1934 for his invention of the centrifuge microscope which has been used in laboratories throughout the world.

JAMES D. LEE, JR.

PUBLICATIONS RECEIVED.

Fundamentals of Photography with Laboratory Experiments, by Paul E. Boucher. 304 pages, plates, illustrations, tables, 16 × 24 cms. New York, D. Van Nostrand Company, Inc., 1940. Price $3.00.

Phenomena at the Temperature of Liquid Helium, by E. F. Burton, H. Grayson Smith and J. O. Wilhelm. 362 pages, illustrations, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1940. Price $6.00.

Introduction to Electricity and Optics, by Nathaniel H. Frank. 397 pages, illustrations, 17 × 24 cms. New York, McGraw-Hill Book Company, Inc., 1940. Price $3.50.

Principles of Direct-Current Machines, by Alexander S. Langsdorf. Fifth Edition, 746 pages, illustrations, 16 × 24 cms. New York, McGraw-Hill Book Company, Inc., 1940. Price $5.50.

Statistical Mechanics, by Joseph Edward Mayer and Maria Goeppert Mayer. 495 pages, illustrations, 16 × 24 cms. New York, John Wiley & Sons, Inc., 1940. Price $5.50.

Principles of Electrical Engineering Series. Electric Circuits, A First Course in Circuit Analysis for Electrical Engineers, by Members of the Staff of the Department of Electrical Engineering, Massachusetts Institute of Technology. 782 pages, illustrations, 16 × 24 cms. New York, John Wiley & Sons, Inc. Price $7.50.

Engineering Surveys, by Harry Rubey, George Edward Lommel and Marion Wesley Todd. Revised Edition, 141 pages, illustrations, tables, 13 × 20 cms. New York, The Macmillan Company, 1940. Price $3.50.

Elementary Quantitative Analysis, Theory and Practice, by Hobart H. Willard and N. Howell Furman. Third Edition, 531 pages, illustrations, tables, 15 × 22 cms. New York, D. Van Nostrand Company, Inc. Price $3.25.

The Early Days of the Power Station Industry, by R. H. Parsons. 217 pages, plates, 16 × 25 cms. New York, The Macmillan Company, 1940. Price $3.50.

New Worlds in Engineering, Chrysler Corporation. 95 pages, illustrations, 22 × 28 cms. Detroit.

Why Britain is at War, by Harold Nicholson. 160 pages, 11 × 18 cms. New York, Penguin Books Inc.

Illinois State Water Survey, Bulletin No. 21, Supplement II. 44 pages, 15 × 23 cms. State Water Survey Division, Urbana.

United States Department of the Interior, Bureau of Mines. Bulletin 426, Quarry Accidents in the United States during the calendar year 1937. 73 pages. Bulletin 428, Metal-Mine Accidents in the United States: 1937. 53 pages. 2 pamphlets, 15 × 23 cms. Washington, Superintendent of Documents.

Bell Telephone System, Monographs: B-1224, A Solution for Faults at Two Locations in Three-Phase Power Systems, by E. F. Vaage. 16 pages, illustrations. B-1225, Electrical Drying of Telephone Cable, by L. G. Wade. 12 pages, illustrations. B-1226, Thermionic Emission, Migration and Evaporation of Barium on Tungsten, by J. A. Becker and G. E. Moore. 14 pages, illustrations. B-1227, Disintegration of Face Brick by Crystallization of Soluble Salt, by J. M. Hardesty. 5 pages, illustrations. B-1228, Wave Shape of 30- and 60-Phase Rectifier Groups, by O. K. Marti and T. A. Taylor. 14 pages, illustrations. B-1229, Rockwell Hardness of Cylindrical Specimens, by W. E. Ingerson. 8 pages, illustrations. B-1230, Analysis of Rockwell Hardness Data, by R. L. Peek, Jr., and W. E. Ingerson. 11 pages, illustrations. B-1231, Electrical Conductance Measurements of Water Extracts of Textiles, by A. C. Walker. 7 pages, illustrations. 8 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1940.

CURRENT TOPICS.

Zinc Melting.—Out of the Kitchen has come the inspiration for the latest important development in the metals industry—the efficient melting of zinc in industry. The humble double-boiler which Mrs. Smith cooks her vegetables to just the proper turn has been adapted, on heroic scale, to smooth the wrinkles from the brows of industrialists plagued with the expense and impurities of conventional methods. Down at the great Glenn L. Martin Company aircraft factory in Baltimore has been developed this useful system, because Martin uses much of the metal in making dies for his famous bombers and overocean transport ships. Patents on the device have been taken out by the Company. Heretofore, zinc has been melted simply by putting it in a pot and then putting fire under the pot. But heat has concentrated at certain points, the zinc has alloyed with the pot metal at these points, and the melted product usually turns up with impurities from the contact. In addition to this, the pots have been short-lived, eroding at the points of maximum heat—an expensive item indeed. It was to produce better metal for die-making and at the same time reduce the cost of pot replacement that the Martin research staff, developed the double boiler idea after six months of experiment. They built a big pot with a combustion chamber underneath (for gas, oil, or coal) and covered it with refractory material. In this they melt lead and into the molten mass they dip another pot containing the zinc. Since the heat thus is evenly distributed over the pot, there is no tendency for the zinc to alloy with the pot, the metal is returned in molten form in a high degree of purity, and the inner pot is spared the eroding effect of the zinc at points of extreme heat. The end-result to the Martin Company has been a great improvement in die materials and a great reduction in the cost of replacement of melting pots. It is believed that the inner pot will last for an indefinite period. It is considered likely that many other industries will be affected by the discovery. In addition to all this, a cheaper grade of steel may be used for the zinc pots. Under the old system, the pots have of necessity been made of expensive steel.

R. H. O.

Lucite Instrument Cases.—Sensitive instruments, as important to the diagnostician of plant equipment ills as the stethoscope is to the physician, are now built directly into solid blocks of crystal-

clear "Lucite" plastic it is announced by E. I. du Pont de Nemours & Company which produces the methyl methacrylate. All parts and processes of the instruments can be observed in the light-weight, shatter-proof blocks, in much the same manner as blood circulation and other bodily functions were observed at a World's Fair exhibit in transparent figures representing human beings. Pioneering with this principle of instrument design, the F. W. Dwyer Manufacturing Company of Chicago has just announced a new pocket carbon dioxide indicator in which passages for the absorbent fluid are drilled and reamed directly into the plastic. No glass tubing or delicate moving parts are used. This instrument must be ready for a life in an environment of bolts, pipes, and boiler heads. It looks as delicate as if it were made of glass. But its "Lucite" body will permit it to take knocks that would shatter glass. The industrial engineer, using the instrument to check whether the plant is getting the most out of its fuel, is able to read the scale with ease even in poorly lighted quarters. Light is admitted from all sides through the transparent material. This frees all components of the instrument from shadow. Simplicity and unusual accuracy, as well as lightness of weight and compactness were achieved with the new design. Drilling indicating tube and chambers directly into the plastic eliminated strains that occur when separate parts are used. The absorbent fluid which indicates the volume of carbon dioxide had no effect on the plastic material. The Dwyer Company has applied the same principle in the production of its portable draft gauges. These instruments are sensitive enough to measure extremely slight fluctuations in pressure or air velocity.

R. H. O.

Human Beings Rank Low on the Mosquito's Menu.—Persons who insist they are the favorite food of all the mosquitoes at a picnic, probably are right, say entomologists of the Federal Department of Agriculture. Some individuals do attract mosquitoes more than others. But horses and cattle are even more attractive to the female mosquito, the only one that bites. Recent work by Federal entomologists bear out earlier investigations and show that when the mosquitoes have free choice they prefer horses and cattle to human beings by about 6 to 1. Pigs were about 3 times as popular as humans. Dogs were lightly preferred. Man rates just ahead of chickens and cats as a preferred source of a blood meal which most of the biting mosquitoes require before they can begin depositing eggs. By a comparatively simple but delicate laboratory procedure known as the precipitin test, the scientist can identify the source of the small quantity of blood in a full-fed mosquito. Checking the

blood sources in a representative collection of mosquitoes reveals the food preferences of the insects. But the mosquito is not a fussy feeder and takes what she can get. Of the mosquitoes captured inside houses more than a third had fed on humans.

R. H. O.

Aircraft Engineering Research Conference.—Dr. Vannevar Bush, Chairman of the National Advisory Committee for Aeronautics, recently announced the decision of the Committee to postpone for one year the Annual Aircraft Engineering Research Conference and Inspection of the Committee's laboratories and Langley Field, Virginia, and that the next such conference would not be held before May, 1941. Dr. Bush stated that the Committee had reluctantly reached the conclusion that it was impracticable to hold the conference this year because of the great increase in the number and importance of urgent research problems now under way and because of the greatly increased pressure of work resulting from the effort necessarily devoted to the design and construction of new research facilities for the Committee's research stations at Langley Field, Virginia, and Moffett Field, California.

R. H. O.

Migrants Go Due West.—In migrating westward, Americans are still tending to travel due west rather than to angle northward or southward. This fact appears in a study of migration into the three Northwestern States of Oregon, Washington, and Idaho, in the years since 1930. A survey by the Bureau of Agricultural Economics and the Farm Security Administration shows that a large part of the migrating families started west from the two Dakotas and Nebraska and from urban centers such as Chicago, Milwaukee, and Detroit. There were relatively few from the south part of the Great Plains. Migrants from Oklahoma and Texas also went due west, and so reached California. Peak years for migration into the Northwest were 1936 and 1937—an echo of the drought years of 1934 and 1936. A more favorable crop year in 1937 was followed by a drop in westward migration in 1938.

R. H. O.

Polaroid Variable Day Glass.—The Polaroid Variable Day Glass is the first eye-protection device that permits the wearer to control the brightness of the view—to reduce outdoor brilliance as much or as little as he pleases. In addition to blocking reflected glare, the new Variable Glasses afford means for instant reduction of the brilliance of a scene to almost any desired point. The value of the

Polaroid Variable Day Glass arises from three facts: (1) Many scenes in ordinary life are too bright for comfortable and efficient vision. (2) The degree of brilliance of different neighboring scenes may vary in large measure. (3) There is a great variation from person to person in tolerance of excessive brightness over extended periods. Unlike any previous device, it makes any brightness right for any normal eyes. With it each eye looks out through two Polaroid lenses. The front lens before each eye is stationary in the frame, while the two rear lenses may be rotated by a convenient button on the bridge of the frame. When this control button is moved to the extreme left, the maximum amount of useful-seeing light reaches the eyes. As the button is moved towards the right, the glasses become gradually darker and darker, until at the extreme right they are so dark that the brightest possible surrounding landscape can be viewed with no discomfort whatsoever. Between these two extremes of adjustment lies an infinite variety of densities —at least one of the densities is sure to suit the eyes. In effect, the Polaroid Variable Day Glass is the equivalent of a whole series of conventional glasses, carefully graduated to pass different amounts of light. In addition to their revolutionary control over brightness they have the optional feature of louvered side shields. The louvers, like Venetian blinds in the plastic shields, effectively block out light that causes back reflections, and transmit light that makes possible clear side vision. Side shields on eye glasses are not a new device. However, these new louvered side shields are the first ever devised that both completely block back reflections, and permit the clear side vision that is so important for automobile driving, boat racing, and other outdoor pursuits.

R. H. O.

Ground-Water Levels in Pennsylvania Make Notable Recovery from Extreme Low Stages.—In January and February of the present year the water levels in about 30 key wells throughout Pennsylvania reached the lowest average stage for these months recorded during the nine years of observation. These low water levels were the result of several months of deficient rainfall during which there was very little ground-water recharge and long-continued decline of ground-water levels. With abundant recent rain and snow there has been heavy ground-water recharge, with the result that in the first two weeks of April the water level reached the highest stage recorded for this time of the year. This remarkable recovery from a record-breaking low stage to a record-breaking high stage is of great practical significance, as it removes a serious threat of impending shortage in water supplies for all those communities that

obtain their water from wells or from spring-fed streams. This information has recently been released by the Geological Survey, U. S. Department of the Interior, which, in cooperation with the Topographic and Geologic Survey, Penna. Department of Internal Affairs, has made weekly measurements of the water levels in the key observation wells since 1931.

R. H. O.

"Electric Eye" Measures Protein in Wheat Flour.—A simple method of determining protein in wheat flour based upon a new principle has been developed by the Agricultural Marketing Service through use of the "electric eye" or photoelectric cell. The new method was described recently by Dr. Lawrence Zeleny, research chemist with the Service, at the annual meeting of The American Association of Cereal Chemists in New York City. According to Dr. Zeleny, the test with the electric eye follows extraction of the protein from the flour and its precipitation in the form of a stable colloidal suspension. This is a chemical process. With the protein in suspension, the ray of the electric eye is passed through a given quantity of the material. Its optical density or resistance to passage of the ray automatically measures the gluten protein content of the flour. Scientists who have developed the process, entirely different from the slower and more laborious process now in general use, say that the results are in good agreement with those obtained by other methods. For routine work the new process saves time, space in the testing laboratory, chemicals, and investment in costly equipment. Efforts are now being made to adapt the new method to determine the protein content of wheat in a way that will permit its use in grain inspection work. Protein content is one of the important quality factors effecting the commercial value of both wheat and wheat flour and the baking qualities of the flour. Present methods for measuring protein require permanently-installed, elaborate and expensive apparatus compared with the equipment used by Dr. Zeleny.

R. H. O.